sierra research

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Development of the CALIMFAC California I/M Benefits Model

prepared for:

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June 1990

prepared by:

Sierra Research, Inc.
1521 I Street
Sacramento, California 95814
(916) 444-6666

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CALIMFAC
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TABLE OF CONTENTS

List of Tables

List of Figures

List of Appendices

I. Summary

A computer simulation model called CALIMFAC ("CALifornia I/M FACtor") has been developed for use in evaluating the effectiveness of the California biennial vehicle inspection, or "Smog Check", program. The model calculates baseline (no inspection program) exhaust emission factors for 1965 to 2004 model year gasoline-powered passenger cars, light-duty trucks and medium-duty vehicles, and predicts emission benefits for calendar years 1980 to 2020 for up to five different sequential I/M program designs. Program options that can be evaluated include inspection frequency, inspection test type, visual/functional check, emission standard stringency, repair cost limits, mechanic performance, model years included, and specific vehicle exemptions. A total of over 200 different I/M program designs can be constructed from the available options, with an infinite combination of start dates and exemptions. Options are selected by the user from a series of menus that prompt for input. Although the model was initially written for execution on a minicomputer, a personal computer version has also been prepared.

Emission factors predicted by the model are somewhat higher than those predicted by the Air Resources Board's emission factor model, EMFAC7D. This is probably due to the model's treatment of malperforming vehicles. It is believed that previous analyses underestimated emissions from malperforming vehicles. The model estimates that the enhanced Smog Check program resulting from the implementation of SB 1997 will reduce exhaust hydrocarbon (HC) emissions by nearly 18%, carbon monoxide (CO) emissions by about 19% and oxides of nitrogen (NOx) emissions by about 12% in 1992, when the program enhancements are fully implemented. HC benefits are predicted to remain fairly constant through 2020 at between 17 and 18%. CO reductions from the

SB 1997 program continue to increase, leveling off at approximately 27% by 2012. NOx emission benefits are projected to peak in the early 1990s at approximately 12%, and then to level off about 2012 at a little over 5 percent. The model also shows that the SB 1997 program changes (two-tier mechanic licensing requirements, increased cost limit for repairs and computerized emission test analyzers) will result in both near-term and long-term program improvements, as shown in Table I-1 below.

Table I-1

Smog Check Program Benefits Projected by CALIMFAC
(Relative to No-I/M Baseline)

	Near-Term			Long-Term		
	HC	CO	NOx	HC	CO	NOx
Original Program	10%	10%	8%	5%	8%	2%
Enhanced Program (SB 1997 fully implemented)	18	19	12	17	27	5
Enhanced Program plus Annual Inspection	30	35	23	22	32	8
Enhanced Program plus Loaded Mode Testing	20	25	15	23	33	15

Sensitivity analyses show that the model is most sensitive to inspection frequency and inspection test type. These results, which are also summarized in Table I-1, indicate that relative to other program parameters evaluated for sensitivity, the implementation of an annual inspection program would result in the largest near-term improvement in HC benefits beyond those already achieved through the implementation of SB 1997. The model predicts that even with no additional improvements to the program, this change would produce HC benefits of nearly 30%, CO benefits of approximately 35% and NOx benefits of well over 20% within about five years of program implementation and HC, CO and NOx benefits of 22%, 32% and 8%, respectively, after about 20 years. The other significant program change that provided the greatest long-term improvement is the implementation of a loaded mode tailpipe test for 1980 and later model year vehicles (20% HC, 25% CO and 15% NOx soon after program implementation, with HC and CO benefits increasing to 23% and 33% in later years). Other program changes to which the model was sensitive include improving the performance of mechanics in identifying and repairing vehicle defects (19% HC, 29% CO and 8% NOx by 2010); and increasing the number of components included in the visual/functional underhood inspection (increases long-term NOx benefits of the program to approximately 8%). Removing the cost limit on repairs would also have small but measurable beneficial effects on the effectiveness of the I/M program.

II. Introduction

The California Air Resources Board (ARB) is the state agency with principal responsibility for coordinating statewide air quality planning and for controlling emissions from motor vehicles. For the Board to effectively carry out these responsibilities, it must have the ability to estimate current emissions levels from motor vehicles, and to predict emissions from vehicles that have not yet been built. To do this, the ARB must have an accurate, up-to-date collection of data about the characteristics of vehicles currently on the road; and accurate and reliable models that can predict the effects of future control efforts.

One of the most important elements of the motor vehicle emissions control program undertaken by the ARB is the vehicle inspection and maintenance (I/M), or Smog Check, program. Under this program, millions of vehicles in the eight major metropolitan areas of California are subjected to a computerized inspection every other year. The inspection includes exhaust emission measurement plus visual and functional checks of emission control components. Approximately 35 percent of the vehicles inspected fail and must be repaired. Although the Smog Check before- and after-repair emission test results show that emissions from most repaired vehicles are reduced, there has been no analytical procedure for determining what emission reductions are actually being achieved by the current program. Further, there has been no simple way to evaluate the effectiveness of the program in future years, or how that effectiveness would change as a result of specific program modifications. Finally, previous estimates of program benefits have always been derived independently of the determination of so-called "baseline" emission factors, intended to represent a "no-I/M" case. This approach is not compatible with a population of vehicles that have been subjected to multiple I/M cycles if there are residual benefits of I/M from one inspection/repair cycle to the next.

A. Purpose of This Study

The purpose of this study was to develop an easy-to-use computer simulation model that would calculate baseline emission factors and inspection/maintenance program benefits and would allow the evaluation of the effects of potential program modifications on the overall effectiveness of the program. The model that has been developed calculates baseline exhaust emission factors for 1965 through 2004 model year gasoline-powered passenger cars, light-duty trucks and medium-duty vehicles, as well as emission factors and benefits for these vehicles in a variety of inspection/maintenance program scenarios. Potential inspection/maintenance program modifications that can be evaluated by the user include requiring annual inspections, eliminating inspections on change of ownership, adding loaded mode testing, increasing the stringency of the tailpipe emission standards and/or the underhood inspection, increasing the cost limit for repairs, improving mechanic performance, exempting new vehicles from the program for some number of years, and varying the maximum age of vehicles in the program.

B. Organization of This Report

This report explains in detail how the model was developed and discusses the emission factors and emission reduction benefits predicted by the model. Instructions for running the model are provided in the "User's Guide to the CALIMFAC California I/M Benefits Model." The source code for the model is published in "Source Code for the CALIMFAC I/M Benefits Model." Both reports are dated May 1990.

The next section of this report explains how the model works. That section contains a discussion of the technical basis for the approach the model takes to calculating emission factors, as well as a brief discussion of the potential limitations of the approach. Section IV describes the analytical approach employed to develop the data used in the model. Section V presents the results of the model, including a comparison of the emission factors developed using this approach to the factors used by ARB in the EMFAC7D emission factor model. The results of analyses of the sensitivity of the model to the various input parameters are also presented in Section V.

Section VI discusses one approach to validating the model results. Finally, Section VII presents conclusions and recommendations with respect to future program, data and model improvements.

III. How the Model Works

CALIMFAC was developed using the basic approach taken by the Environmental Protection Agency (EPA) in developing the I/M credits model, called the TECH IV model, for 1981 and later model year vehicles. The basic assumptions underlying this approach are:

- Different vehicle emission control technologies behave differently under in-use conditions in terms of their emissions, their response to an I/M test, and their response to repair techniques.

- The emissions performance of vehicles (or groups of similar vehicles) can be characterized by quantum changes in emissions between discrete levels, or regimes, rather than as continuous functions.

- The effect of vehicle emission system deterioration and component malfunctions can be represented by movement of vehicles among regimes, rather than as a change in the characteristic emissions within the regimes.

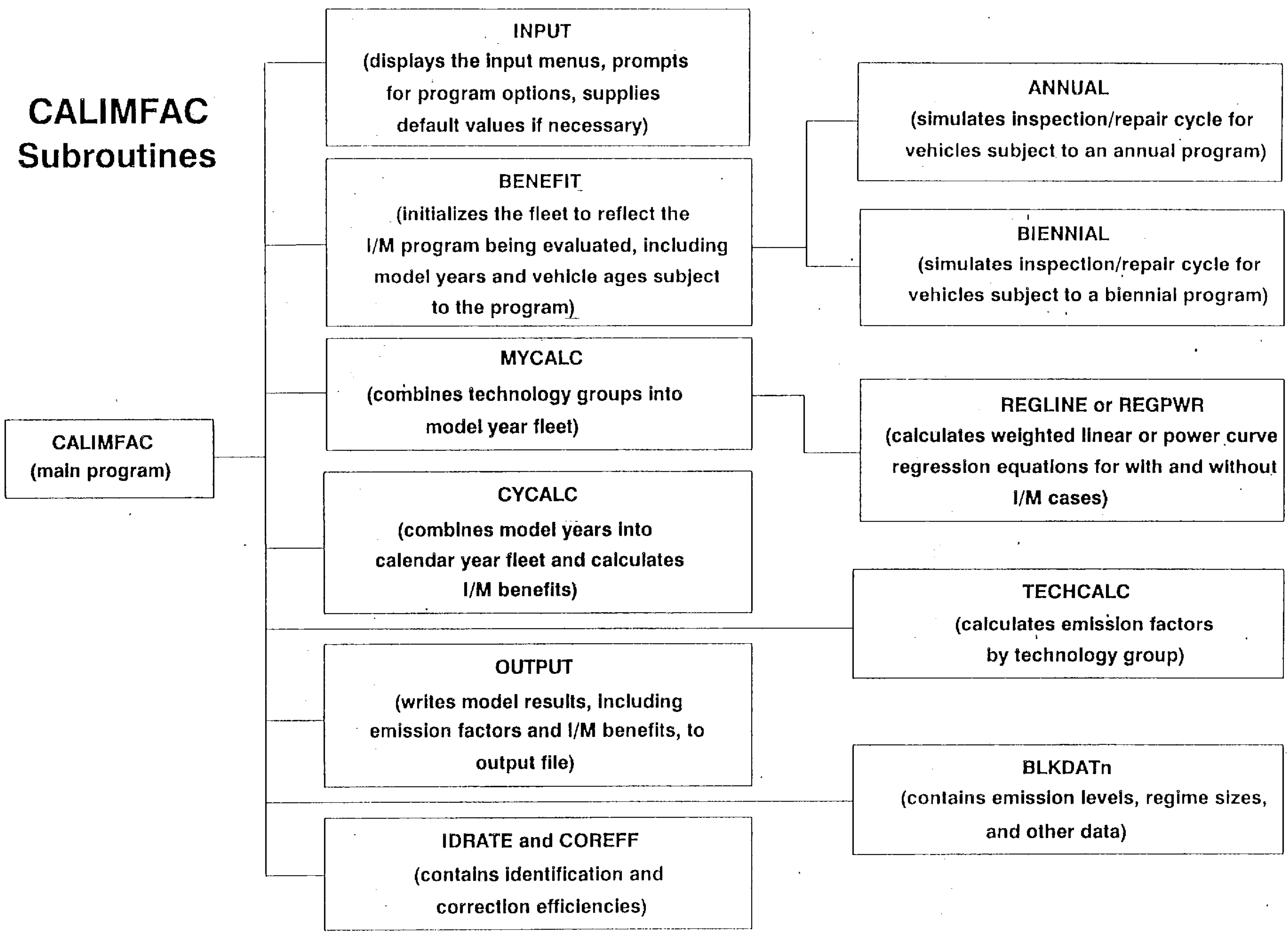
Using these assumptions, the fleet can be divided into technology groups and emission regimes, and characteristic emission levels can be assigned to each combination. Emissions increases due to deterioration and decreases due to repair are simulated by changing the relative sizes of the emission regimes for each technology group. All calculations are done on an emission control technology group and pollutant specific basis. The schematic in Figure III-1 shows the basic structure of the model, and the sequence in which calculations are performed.

The main program, called CALIMFAC, calls each of the subroutines in the second column in the order shown. The first module, INPUT, displays the program option menus and prompts for inputs. This module provides default values for program options if none are supplied by the user. The main program calculates baseline (without I/M) emission factors and then, if the I/M benefits feature of the model has been selected, calls BENEFIT. Subroutine BENEFIT initializes the fleet to reflect the I/M program options being evaluated, and then calls either the ANNUAL or BIENNIAL subroutine, as appropriate. The ANNUAL and BIENNIAL subroutines simulate the inspection/repair/deterioration cycles that occur throughout the life of the vehicles in the program, and generate a set of with-I/M emission data points used to develop with-I/M emission factors.

Figure III-2 shows how the model simulates deterioration in the absence of an I/M program. The vehicle population is divided into emission regimes, which are selected to represent vehicles with similar in-use emissions performance. Deterioration is represented by changes in the relative population sizes of the regimes. For example, the size of the "super", "very high" and "high" emitter regimes all increase as the vehicles age, while the fractions in the lower emitting regimes are reduced.

Figure III-3 shows how an I/M program affects the movement of vehicles among regimes. The I/M program adjusts the relative population

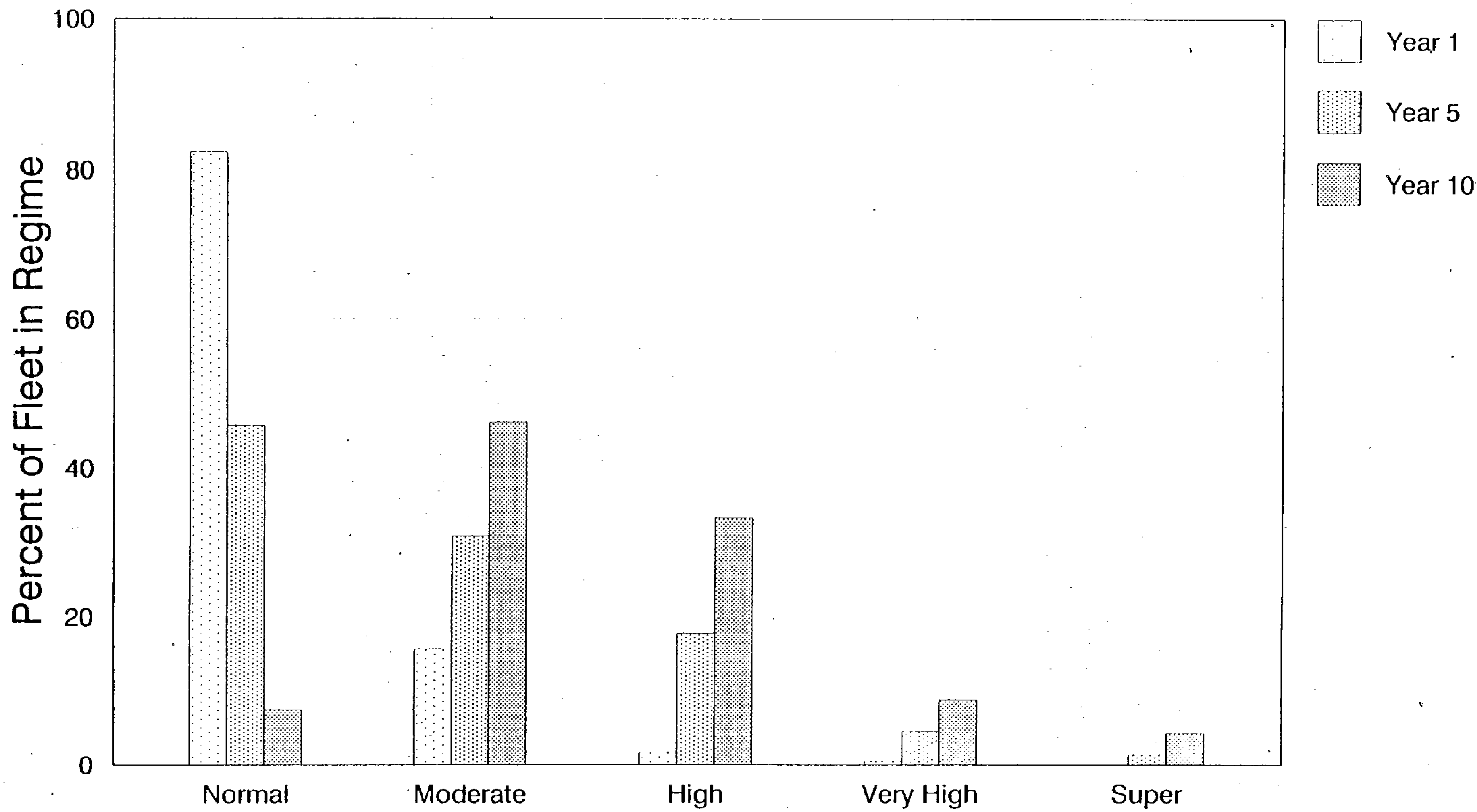
Figure III-1



CALIMFAC
Subroutines
CALIMFAC
(main program)
INPUT
(displays the input menus, prompts for program options, supplies default values if necessary)
BENEFIT
(initializes the fleet to reflect the I/M program being evaluated, including model years and vehicle ages subject to the program)
MYCALC
(combines technology groups into model year fleet)
CYCALC
(combines model years into calendar year fleet and calculates I/M benefits)
OUTPUT
(writes model results, including emission factors and I/M benefits, to output file)
IDRATE and COREFF
(contains identification and correction efficiencies)
ANNUAL
(simulates inspection/repair cycle for vehicles subject to an annual program)
BIENNIAL
(simulates inspection/repair cycle for vehicles subject to a biennial program)
REGLINE or REGPWR
(calculates weighted linear or power curve regression equations for with and without I/M cases)
TECHCALC
(calculates emission factors by technology group)
BLKDATn
(contains emission levels, regime sizes, and other data)

Figure III-2

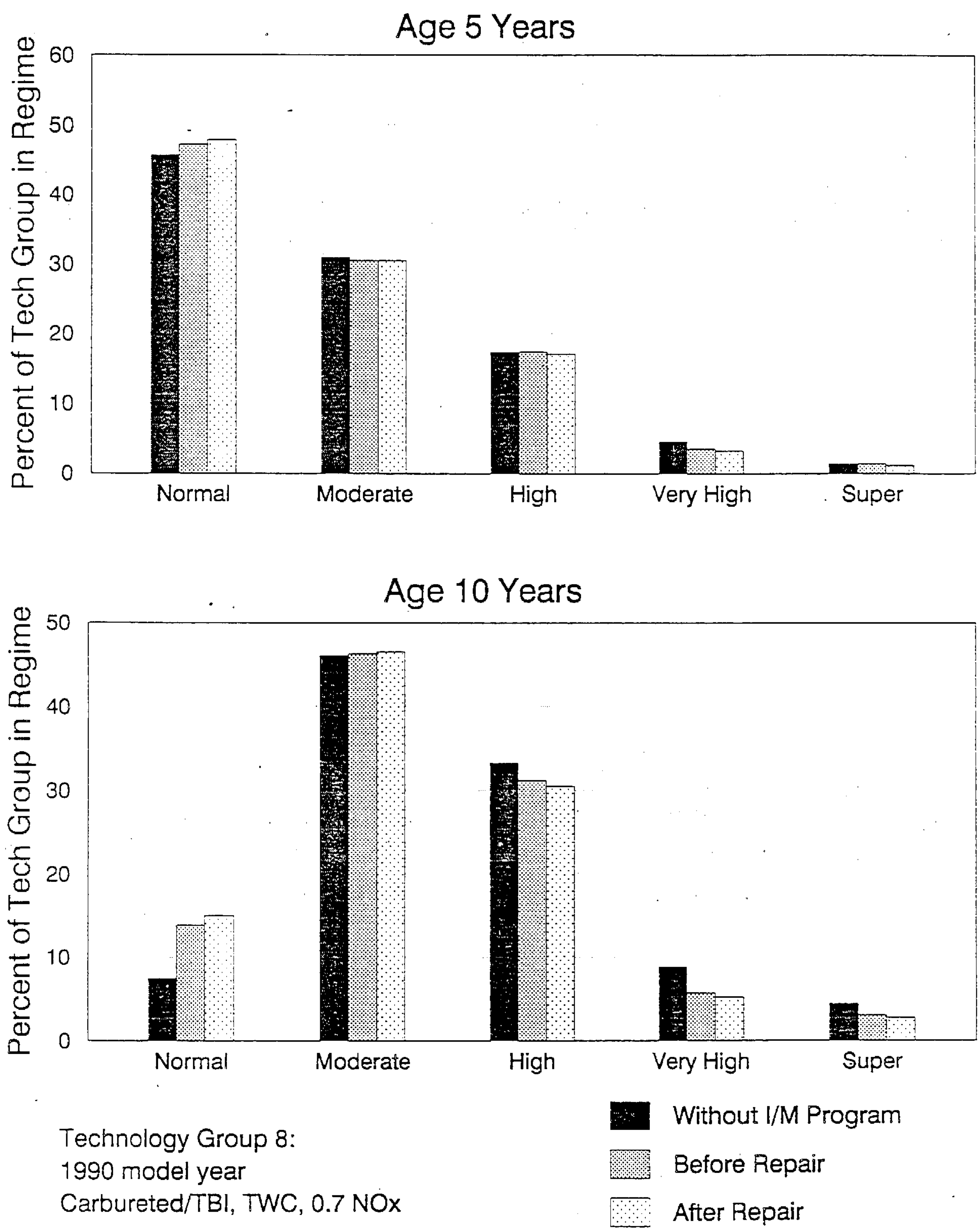
Effect of Deterioration on Regime Sizes Without I/M



Technology Group 8:
1981 and later model years
Carbureted/TBI, TWC, 0.7 NOx

Figure III-3

Effect of Repair on Regime Sizes With Default I/M Program



Technology Group 8:
1990 model year
Carbureted/TBI, TWC, 0.7 NOx

fractions, in this case by increasing the fraction of vehicles in the "normal" and "moderate" regimes while decreasing the fractions in the higher emitting regimes. Then deterioration occurs, shifting population fractions in the opposite direction. Figure III-3 illustrates that the benefits of the I/M program come not only from the difference in emissions before and after repair, but also from slowing the migration of vehicles into higher-emitting regimes. Although the differences in regime sizes between the without I/M case and the before and after repair cases may appear small, the very high and super emitters have very high emissions relative to the normal and moderate emitters. Therefore, a small change in the sizes of these high-emitting regimes has a large impact on emissions from the vehicles. In the example shown, the exhaust emissions from the 5-year old vehicles in Tech Group 8 after repair are 6% lower than they would be with no I/M program; by the time the vehicles are 10 years old, the benefit has increased to 16%.

The algorithms used to adjust the population sizes, and the data used to develop those algorithms, are discussed in more detail below.

The model can simulate changes in I/M program design that may occur during a vehicle's life. Consequently, at the end of each simulation year, the model checks to see whether any I/M program features have been changed, and makes appropriate adjustments. For example, if the inspection frequency changes from biennial to annual, the program exits the BIENNIAL subroutine and continues the simulation in the ANNUAL subroutine. Up to five different sequential I/M program designs can be evaluated in this manner.

The calculations up to this point are done on an emission control technology system-specific basis. The emissions data for each technology group are passed to subroutine MYCALC, where the technology groups are combined into model year fleets. Then subroutine REGLINE calculates weighted regression equations for both the with- and without-I/M cases. At the present time, and based on directives from the Air Resources Board staff, the default regressions are performed to generate two straight lines with a "flex" point. The flex points are dynamically determined by the model for each technology group, model year and pollutant.[1] However, the model also offers the option of selecting either a simple single-line linear regression (also performed within the REGLINE subroutine) or a power curve regression (within the REGPWR subroutine).

Subroutine CYCALC uses regression equations and VMT data to combine 25 years of emission factors into calendar year emissions, and to calculate I/M program benefits. This feature is particularly useful for policy-level decision makers, in that the model's complex calculations are reduced to a single percentage reduction for each pollutant and calendar year.

At the user's option, the technology group-specific emissions estimates are subjected to a regression routine in the TECHCALC module. These regressions can be useful for engineering analyses or "what if" exercises.

The OUTPUT module writes the model results to the output file chosen by the user. The user has the option of selecting a variety of levels of detail for the model's output.

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1. As described above, regime sizes are recalculated at the end of each AGEYR to account for changes resulting from vehicle deterioration and repair. These calculations are performed on a technology group basis. At the point when the size of the normals becomes zero, the overall deterioration of the fleet emissions appears to slow down; therefore, the flexpoint is placed at this AGEYR. This change in deterioration occurs because the migration rates are much higher per 10,000 miles for normals than for other regimes, and when the normals have all migrated to higher regimes the deterioration rate tends to slow down. When technology groups are combined into model years, the flexpoint for each model year is the earliest flexpoint of any technology group that makes up that model year.

The Block Data subroutines 1 through 3, shown in Figure III-1 as BLKDATn, and the data files IDRATE and COREFF, contain all the data needed to calculate emission factors and inspection/repair benefits for any of the program option combinations available through the input menus. The data used in the model were developed through an extensive analysis of available California vehicle emission test results. Data bases used were the Light Duty Vehicle Surveillance Programs 1 through 9, the I/M Evaluation Program, and the Random Roadside Inspection Programs carried out in 1985 and 1986. The data analysis techniques are described in detail in Section IV of this report.

A. Calculating Emission Factors

The following example shows how emission factors are calculated for each pollutant and model year:

1. For each year of a vehicle's 25-year life, the model calculates the size of each emissions regime and the emissions from each regime, using the odometer reading for a vehicle of that age.

   Sample calculation: At age 5, the average vehicle has an odometer reading of 58,869 miles. For Tech Group 14, the percent of the technology group in each hydrocarbon emission regime is given by the following equations:

Supers:	.007973/10,000 miles * 58,869 miles = 4.694%
Very Highs:	-.04015 + .032067/10,000 miles * 58,869 miles = 14.863%
Highs:	.042525/10,000 miles * 58,869 miles = 25.034%
Moderates:	.29025 + .001140/10,000 miles * 58,869 miles = 29.696%
Normals:	1 - .04694 - .14863 - .25034 - .29696 = 25.714%

The hydrocarbon emission levels of each regime are:

Supers:	4.50 g/mi
Very Highs:	2.58 g/mi
Highs:	1.27 g/mi
Moderates:	0.546 g/mi
Normals:	0.291 g/mi

2. Using the relative size and characteristic emissions for each regime, emissions at the mileage corresponding to each of the 25 years are calculated. These steps are repeated for each technology group.

   Sample calculation: The total hydrocarbon emissions from Tech Group 14 at the age of five years are:

Supers:	4.694% * 4.50 g/mi	= 0.2112 g/mi
Very Highs:	14.863% * 2.58 g/mi	= 0.3835 g/mi
Highs:	25.034% * 1.27 g/mi	= 0.3179 g/mi
Moderates:	29.696% * 0.546 g/mi	= 0.1620 g/mi
Normals:	25.714% * 0.291 g/mi	= 0.0748 g/mi
Total:		1.1494 g/mi

3. For each of the 25 model years, emissions from technology groups represented in the model year are combined according to their proportion of model year sales.

   Sample calculation: The results of similar calculations for the other technology groups represented in the 1980 model year are shown below. Also shown are the fraction of new car sales in the model year for each technology group, and the weighted sum of emissions from 1980 model year vehicles at the age of five years.

Tech Group	Sales Fraction	Total Emissions
5	26.5%	3.201 g/mi
6	11.4%	1.458 g/mi
10	12.7%	1.073 g/mi
14	49.4%	1.149 g/mi
Weighted Sum of Total Emissions:		1.718 g/mi

4. Using the 25 years of emissions vs. mileage data from step 3, the model calculates a regression line or curve. The emission factor can then be expressed as an intercept (zero-mile emissions) and a slope (deterioration rate as a function of mileage). Figure III-4 shows the calculated emission rates as a function of age and the resulting regression line.

B. Calculating I/M Benefits

Like the emission factors, the inspection and repair benefits in the model are calculated for each model year. After baseline (without I/M) emission factors are calculated for a model year, the inspection and repair subroutines are executed. The procedure for calculating inspection and repair benefits is shown in the flow chart in Figure III-5.

The first step is a determination of the age of the vehicle in the model year at its first inspection. As described above, deterioration of emissions with vehicle age is simulated in this model by the movement of vehicles to higher-emitting emission regimes. Therefore the age of the vehicles in the model year at their first inspection determines what proportion of the model year fleet will be in each emissions regime at the time the first inspection is performed.

Once the size of each emission regime at first inspection has been determined, the model uses the program options entered by the user to find the appropriate values of identification rate and correction efficiency for the pollutant and technology group being modeled in the current step. The identification rate is a function of the emissions regime before repair (for example, vehicles with major defects are usually easier to find than those with marginally high emissions, so identification rates for supers are generally higher than those for moderates), the type of emissions test, the stringency of the test standards, the type of functional check performed, and the ability of the mechanic to perform the test, as well as the pollutant and

Figure III-4

Development of Emission Factor Equations
Exhaust Hydrocarbons, 1980 Model Year PCs

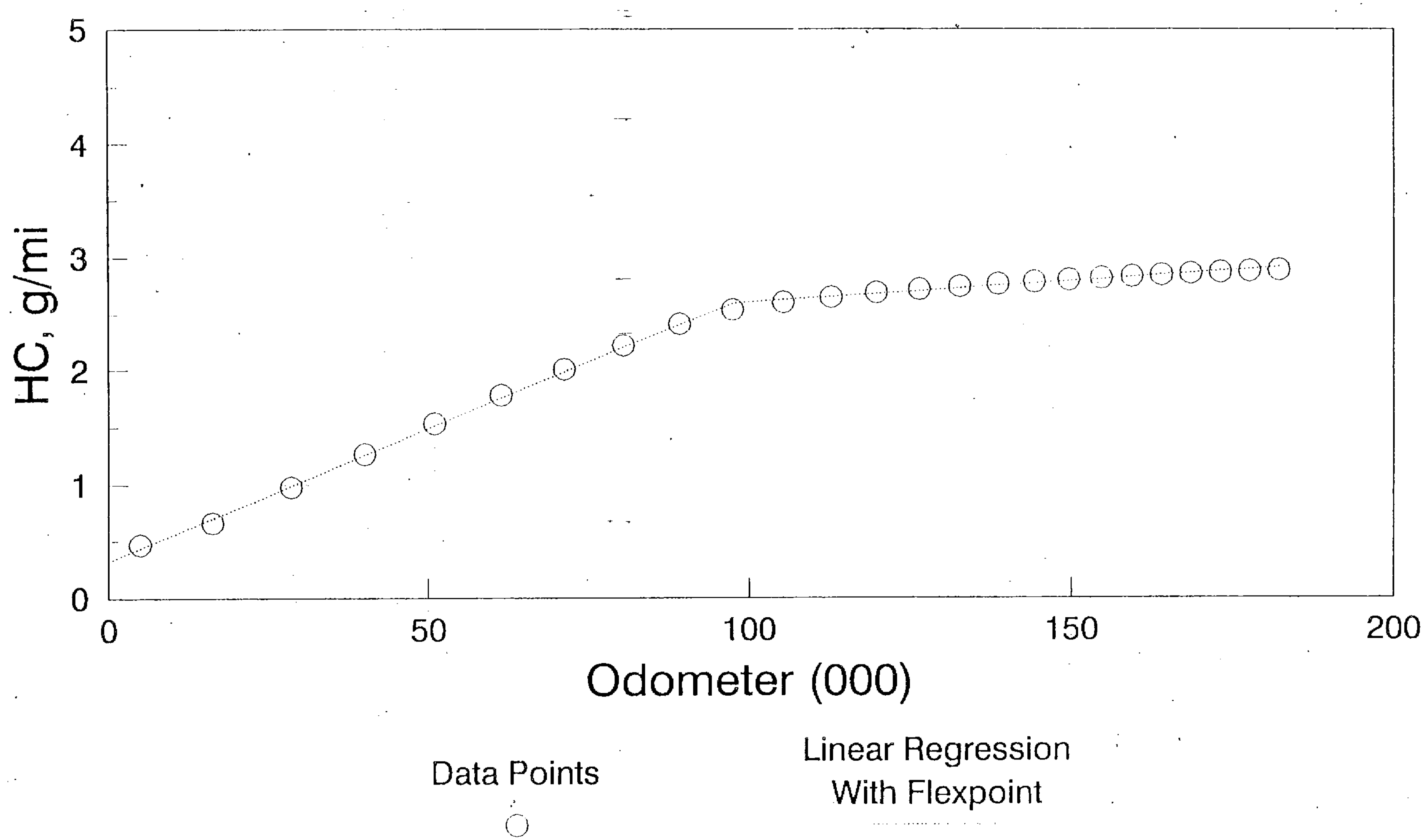
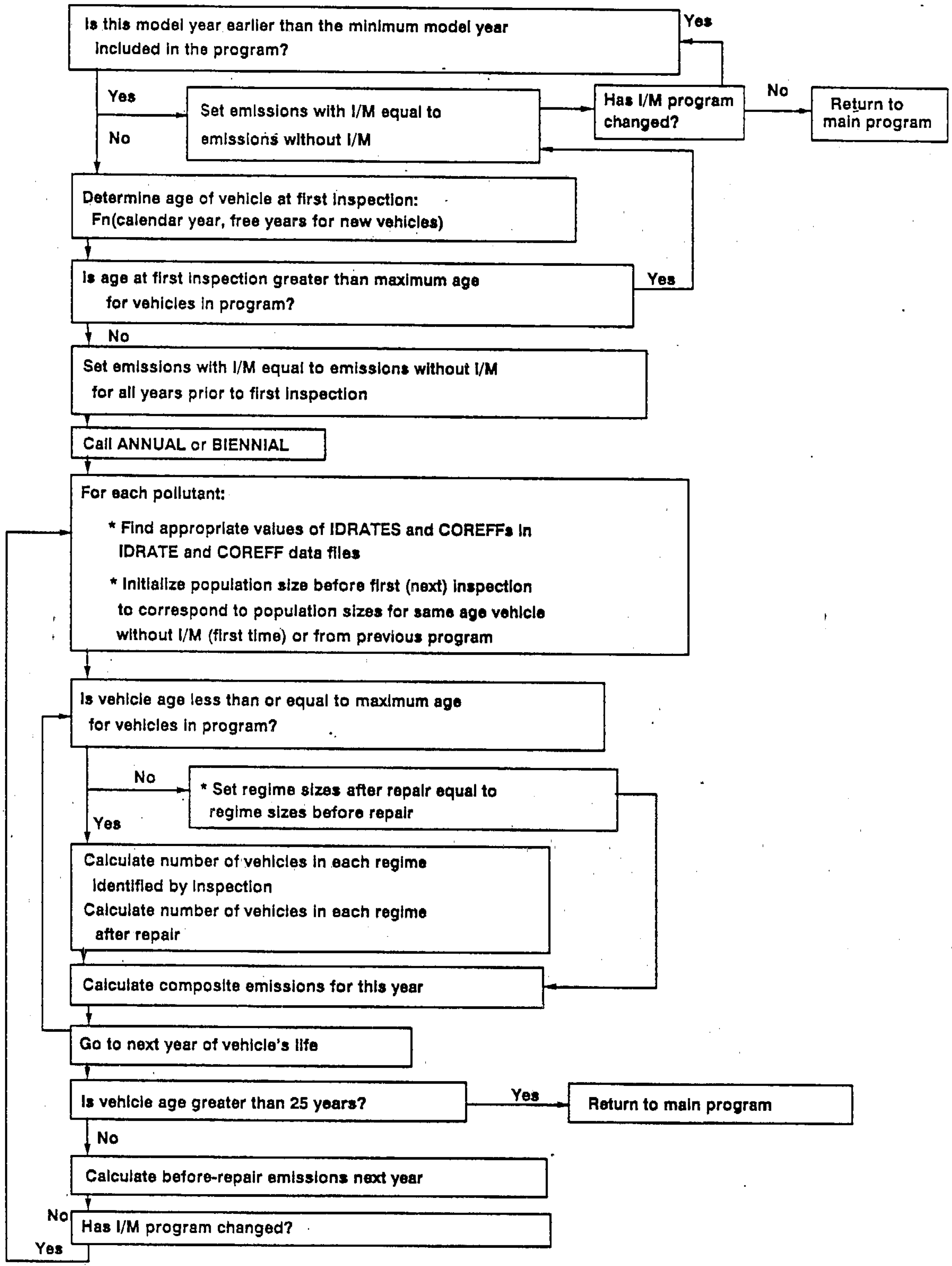


Figure III-5

California I/M Benefits Model: Inspection/Repair Module Detail

Note: Call from main program passes model year to subroutine BENEFIT



technology group. The identification rate is expressed as a fraction, and it is applied to the fraction representing the size of the regime before repair to indicate how many vehicles are subject to repair. Development of the identification rates is described in Section IV.G. of this report.

The correction efficiency is determined by the type of functional check performed, the ability of the mechanic to perform the repairs, and the cost limit imposed on required repairs, as well as the pollutant and technology group. The development of the correction efficiencies is described in detail in Section IV.H. A correction efficiency is provided for each preinspection and postrepair regime combination. Therefore there is a 5 by 5, or 25 element, matrix of correction efficiencies for each combination of program options. For example, for a particular set of program options, 45% of Very High emitters identified by the inspection might be repaired to the Normal regime and 25% to the Moderate regime, with 30% receiving no benefits from repair. The corresponding line in the correction efficiency matrix would look like this:

Pre-repair	Post-repair Regime				
Regime	Normal	Moderate	High	Very High	Super
Very High	0.45	0.25	0.0	0.30	0.0

The fractional value describes the percentage of the vehicles in a certain preinspection regime that moves to a given regime after repair. In calculating the size of the post-repair regimes, the correction efficiency fractions are applied to the portion of the vehicles that was identified, or failed, by the inspection. Thus the size of a regime after repair is equal to the size before inspection, minus the vehicles moving to other regimes due to repair, plus the vehicles moving into the regime from other regimes as a result of repair.

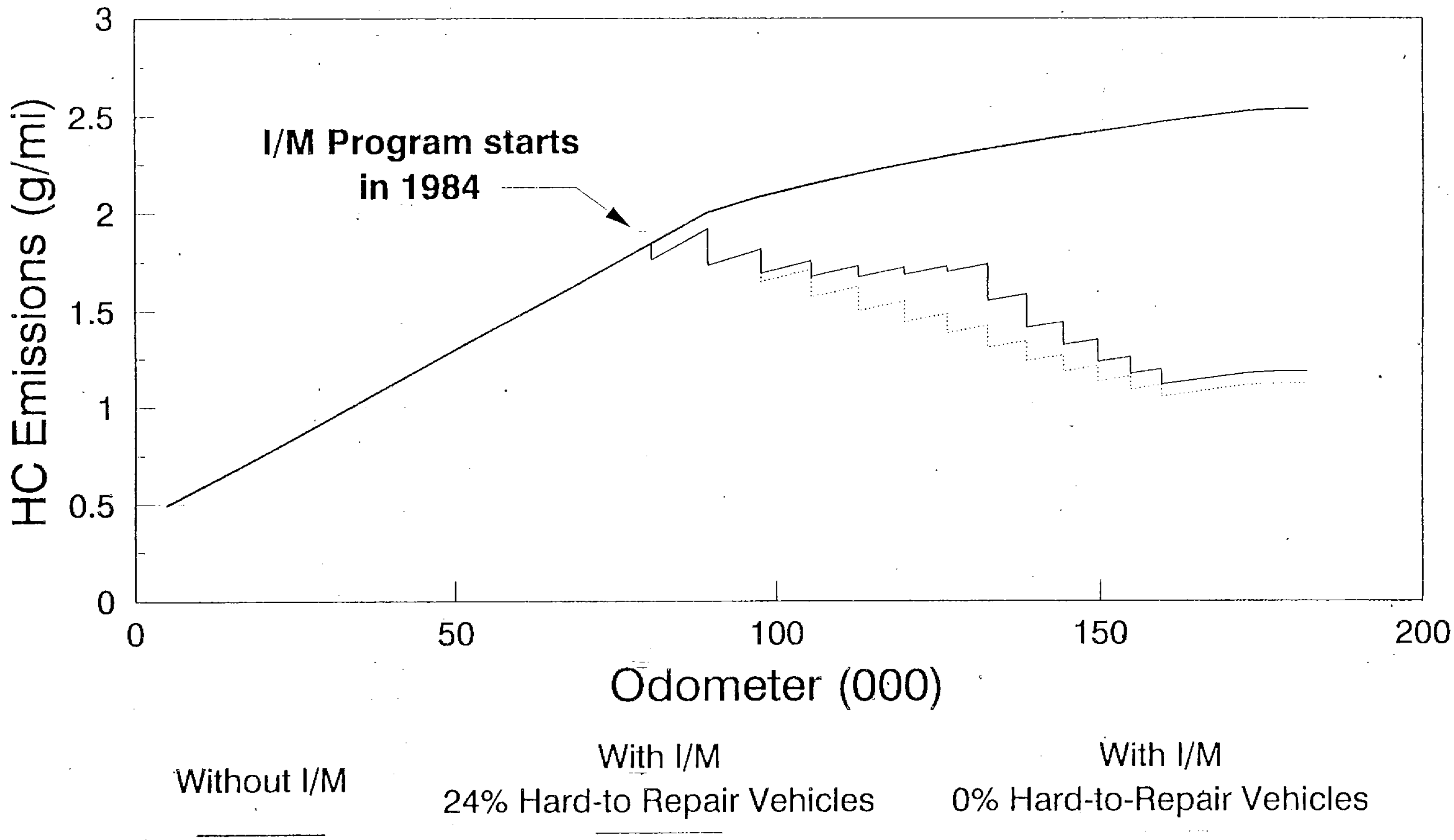
One of the assumptions in this approach is that vehicles moving to a regime as a result of repair behave the same way as vehicles that move to the regime as a result of deterioration. This means that possible effects of I/M such as tampering deterrence or any kind of accelerating effect on emissions deterioration are not accounted for. This assumption is discussed in more detail in Section IV.

The CARB staff believes that under an I/M program having both low repair cost limits and minimal mechanic training requirements, there will be a group of vehicles that will not be repaired. At the direction of the CARB staff, for the 1984 I/M program, which has a $50 repair cost limit and the lowest level of mechanic performance, an assumption is made that 24% of failed very high- and super-emitting vehicles will not be repaired. It is further assumed that since these "hardcore" failing vehicles cannot be repaired when initially detected, they will not be repaired in subsequent I/M cycles. As a result, the population of unrepaired very high and super emitters increases with time. This 24% hard-to-repair fraction applies only to the second and later years of an I/M program having the lowest repair cost limits and mechanic training requirements. Because the program enhancements implemented in 1990 increase the repair cost limits and improve mechanic training, this assumption (and the 24% fraction) affects only the first six years of the California program.

While the 24% fraction is a default value for the original I/M program, the fraction can be changed by the user as an input option. Because the fraction applies only to the 1984 I/M program in California, its impact is most noticeable on the with-I/M emissions factors for pre-1985 model year vehicles. The effect of the assumption regarding hard-to-repair vehicles is illustrated in Figure III-6, which shows before- and after-repair exhaust HC emissions from 1977 model year cars equipped with oxidation catalysts and secondary air injection.

Figure III-6

Influence of Hard-to-Repair Vehicles On Exhaust Hydrocarbon Emissions 1977 Model Year OxCat with AIR



The influence of the hard-to-repair vehicles becomes noticeable in the third year of the I/M program for these vehicles, as shown by the divergence of the with-I/M lines. With no hard-to-repair vehicles, emissions trend steadily downward until the vehicles exit the program at the age of 20 years. However, the assumption that 24% of the vehicles are hard to repair steadily reduces the pool of repairable vehicles. This can be seen in the flattening and rising of the middle line between about 100,000 and 130,000 miles. However, with the implementation of higher cost limits and more-stringent mechanic training requirements in 1990, the model once again allows these vehicles to be moved to lower regimes after repair and the line trends downward more sharply. It is interesting to note that the with-I/M lines on the figure never meet; the assumption regarding hard-to-repair vehicles affects with-I/M emissions and program benefits even after the more stringent program is implemented.

Once emission regime sizes have been calculated, the model applies the emission factors for each regime to produce a composite emission level at the mileage level corresponding to each vehicle age (see Step 3 above). Just as in the baseline case, technology group emissions are weighted and combined to produce model-year specific emission levels for those mileage levels; then 25 years of emission vs. mileage data are regressed to determine zero-mile and deterioration emission rates for vehicles in the specified I/M program in each model year.

C. Calculating Calendar Year Emissions and I/M Program Benefits

Calendar-year emissions are calculated based on the assumption that 25 model years contribute to on-road vehicle emissions in a given calendar year. The emissions from each model year at the mileage level corresponding to the calendar year being evaluated are combined to develop average emissions for the calendar year. The results of this calculation for the with-I/M case are compared with the results from the baseline case to calculate I/M program benefits.

IV. Data Analysis

The emissions data used by the CALIMFAC model in calculating emission factors and inspection/maintenance program benefits were derived from three sets of California vehicle test data.

Light Duty Vehicle Surveillance Programs 1-9: Under CARB-run surveillance programs, over three thousand passenger cars and light trucks sampled from customer service have been tested in the laboratory over the course of many years. Diagnostic information for the surveillance cars indicates what types of defects were present and whether they would pass an I/M test. Data available for these vehicles include FTP emissions before and after various levels of repair. Data for approximately 2600 passenger cars, with model years ranging from 1968 to 1986, are contained in the surveillance data. These data provide information about the emissions behavior of in-use vehicles and potential emissions reductions possible from various levels of repair.

Undercover Cars: In the 1985 I/M Evaluation Program, vehicles that should have failed the California Smog Check tests were selected at random from the general population before they were due to go through the Smog Check program. The vehicles were given comprehensive tests at the CARB's El Monte laboratory before they were taken to randomly selected Smog Check stations. After the completion of Smog Check tests and repairs, the vehicles were returned to the CARB laboratory where another FTP test was conducted. In some cases, CARB technicians performed further repairs of the vehicles and tested them again. These data provide information about how well Smog Check mechanics are able to identify and repair vehicles that should fail the I/M test.

Roadside Survey Data: These data represent field survey test results on thousands of vehicles stopped at California Highway Patrol roadblocks and inspected by CARB and BAR staff. In addition to an extensive visual inspection, each vehicle had tailpipe emissions measured using the same test procedure that is used in the Smog Check program. These data provide the most accurate source of information available regarding the existence of tampering and other defects in motor vehicles.

A. Component Malperformance

One critical decision in the development of the model was how to account for tampered vehicles. In previous models developed by EPA and CARB, tampered vehicles were removed from the data base before the data were analyzed. Separate emission factors and growth rates were developed for tampered vehicles, and these were used as tampering emissions offsets to adjust the factors calculated for the non-tampered fleet. The CARB staff developed these offsets manually; the EPA staff wrote a complex set of subroutines to calculate tampering offsets as part of the MOBILE4 computer model.

A major concern with this approach was that removing tampered vehicles from the data base made an already small data set even smaller. Further, the analysis of emissions from tampered vehicles is based on an extremely small data sample. This approach also requires that the modeler make assumptions about future tampering rates.

The approach taken in this modeling effort was to consider tampering to be similar to any other malfunction that causes vehicles to fail, so that component malperformance could be handled implicitly within the model. This approach required that the proportion of tampered vehicles in the fleet from which the data were developed match the true proportion of tampered vehicles on the road. However, Table IV-1 shows that component malperformance rates observed in the surveillance data are much lower than those observed in the Random Roadside program for some years. As discussed above, the Random Roadside Inspection program is believed to provide the most accurate indication of component tampering and malperformance levels. Emission factors

Table IV-1

Comparison of Underhood Inspection Results

--- Failure Percentage by Type of Malfunctioning Device[2] ---

	AIR	CAT	SPARK	EVAP	EGR	LEAD	O2S	PCV	TAC
Pre-75 Model Years									
Surv	0.4%	--	9.8%	0.0%	2.0%	--	--	0.0%	2.0%
85 RR	8.9	--	17.9	17.2	17.7	--	--	17.9	33.0
86 RR	9.3	--	18.9	20.0	24.9	--	--	19.3	29.6
1975-79 Model Years									
Surv	2.6%	1.1%	28.3%	0.6%	11.6%	0.2%	0.3%	0.8%	5.4%
85 RR	9.4	3.7	6.4	8.7	29.8	8.2	0.0	5.8	16.3
86 RR	10.2	3.4	6.6	10.8	40.7	8.7	0.1	9.7	18.2
1980+ Model Years									
Surv	5.5%	4.3%	11.3%	2.6%	6.9%	0.1%	7.4%	1.7%	3.9%
85 RR	1.0	0.3	0.7	0.7	4.2	1.0	0.4	1.3	2.5
86 RR	1.9	0.7	1.2	1.6	6.0	1.4	0.3	1.6	3.6

Notes: "Malfunctioning" includes <u>all</u> devices identified by inspectors as not properly operating, including tampered, missing, modified, plugged, etc.

Surv - Surveillance programs 1-9, passenger cars only.
85 RR - 1985 Random Roadside Survey
86 RR - 1986 Random Roadside Survey

2. "AIR" means air injection ("smog pump") systems; "CAT" means catalytic converters; "SPARK" means spark advance controls; "EVAP" means evaporative emission control systems; "EGR" means exhaust gas recirculation systems; "LEAD" means the fillpipe lead restrictor (to prevent the use of leaded gasoline in catalyst equipped vehicles); "O2S" means the oxygen sensor and closed-loop control system on computer controlled vehicles; "PCV" means the Positive Crankcase Ventilation System; and "TAC" refers to the thermostatically controlled air cleaner system.

calculated without some adjustment for underrepresentation of tampering would not accurately reflect on-road vehicle emissions. Therefore, the surveillance data had to be adjusted so that tampered vehicles were properly represented. It was for this adjustment that the I/M Evaluation vehicles were used.

In many ways, the I/M Evaluation data were the preferable vehicle data to use for evaluating and projecting vehicle emissions. I/M Evaluation data were coded in a consistent and easier-to-use format while the surveillance data were collected over a number of years, and the data format changed several times. The comparison of odometer readings for the two sets of data by model year group, shown in Table IV-2, indicated that the I/M Evaluation program vehicles had a much higher average mileage.

Table IV-2

Comparison of Average Odometer Readings: Surveillance Program vs. Undercover Cars

Model Year Group	Average Odometer Readings		% of Odometers Over 50,000 Miles	
	Surv.	I/M Eval.	Surv.	I/M Eval.
Pre-1975	77,994	111,197	84%	95%
1975-79	35,005	82,436	24%	85%
1980+	44,537	51,819	38%	47%

This meant that surveillance vehicles were tested early in their lives, and that projections of future emissions performance would be based on a small and limited data set. On the other hand, the I/M Evaluation vehicles had been in owners' hands longer, so their maintenance patterns were fairly well established. Thus, their emissions could be considered more representative of actual, in-use vehicle performance. The one major drawback to using the I/M Evaluation vehicles was that they are all "should-fail" vehicles. To simply add them to the surveillance vehicles would have seriously biased the data set by loading it with high-emitting vehicles. Therefore, these vehicles were used selectively to make the malperformance rates in the surveillance data consistent with the rates observed in the random roadside programs.

The approach taken in augmenting the surveillance data base was to divide the fleet into three main model year groups, and to attempt to duplicate component malperformance rates on a model year group basis for the pre-1980 vehicles. I/M Evaluation program vehicles with specific component malfunctions were added to the surveillance data by model year group until the malperformance rate for the specific component matched that observed in the random roadside program, or until the vehicles in the appropriate model year group with the needed component malfunctions had all been added. In the latter case, once the I/M Evaluation vehicles had all been used, vehicles from the new master data set, which combined vehicles from both programs, were duplicated until the component malperformance rate had been adjusted to match the Random Roadside-observed rate. The malperformance rates by component and model year group in the master data set after adjustment are shown in Table IV-3.

The 1980 and later model year group was not augmented. Unlike the pre-1980 groups, in which the malperformance rates were generally lower that those observed in the random roadside inspections, this group exhibited generally higher malperformance rates. Because the group of 1980 and later vehicles was relatively small, vehicles would have had to be duplicated several times to match the rates observed in the random roadside inspection for these vehicles. Because adjustments were not made to this group, malperformance rates and thus I/M benefits may be slightly overpredicted for this group.

It is important to note that malperformance rates were adjusted by model year group rather than by emission control technology group, due to the small sizes of technology group/malperformance subgroups. Because the emissions and I/M benefits analyses were done on a

Table IV-3

Component Malperformance Rates by Model Year Group in the Master Data Set

	-- Failure Percentage by Type of Malfunctioning Device --								
	AIR	CAT	SPARK	EVAP	EGR	LEAD	O2S	PCV	TAC
Pre-1975 Model Years									
Surv	0.4	--	9.8	0.0	2.0	--	--	0.0	2.0
Master	9.6	--	12.3	5.1	17.1	--	--	3.4	17.3
85 RR	8.9	--	17.9	17.2	17.7	--	--	17.9	33.0
86 RR	9.3	--	18.9	20.0	24.9	--	--	19.3	29.6
1975-79 Model Years									
Surv	2.6	1.1	28.3	0.6	11.6	0.2	0.3	0.8	5.4
Master	9.5	3.3	22.2	4.4	28.4	8.2	0.2	5.4	14.4
85 RR	9.4	3.7	6.4	8.7	29.8	8.2	0.0	5.8	16.3
86 RR	10.2	3.4	6.6	10.8	40.7	8.7	0.1	9.7	18.2
1980 and Later Model Years									
Surv	5.5	4.3	11.3	2.6	6.9	0.1	7.4	1.7	3.9
Master	5.5	4.3	11.3	2.6	6.9	0.1	7.4	1.7	3.9
85 RR	1.0	0.3	0.7	0.7	4.2	1.0	0.4	1.3	2.5
86 RR	1.9	0.7	1.2	1.6	6.0	1.4	0.3	1.6	3.6

Notes:
- Surv: Surveillance programs 1-9, passenger cars only, before adjustment.
- Master: Combined surveillance and I/M evaluation data.
- 85 RR: 1985 Random Roadside Survey
- 86 RR: 1986 Random Roadside Survey

technology-group specific basis, an overweighting of vehicles with component malfunctions in one technology group could occur, resulting in a prediction of overly high emissions from that technology group. This would lead to possible underrepresentation and corresponding low emission estimates in another technology group. Because technology groups are combined to form model year fleets, these effects should tend to counteract one another.

As the data in Table IV-3 show, component malfunction was most significantly underrepresented, and thus required the most enhancement, in the pre-1980 model year groups. By calendar year 1995, these vehicles are over 15 years old and because of their relatively low VMT, do not contribute significantly to either on-road emissions or I/M benefits. Therefore, any error induced by the approach of correcting by model year group instead of technology group would be relatively insignificant by that time.

B. Technology Groups

One of the basic assumptions in this modeling approach is that the emissions behavior of vehicles can be characterized by their emission control technology; then the model can perform calculations for some small number of technology groups, rather than for thousands of individual vehicles. The selection of appropriate technology groups had to meet three goals:

- Each group had to be distinct enough that the vehicles included could be considered to behave essentially identically;

- Each group had to be broad enough that it would contain a sufficient number of vehicles to allow a meaningful analysis; and

- The groups had to be structured in a way that would allow analysis of vehicles incorporating untested control technologies and various levels of emission standards.

Thirteen emission control technology groups were identified initially to represent vehicles in the master data set. These thirteen were reduced to ten when it was determined that some distinctions were not needed in early model year vehicles because their emissions had a minimal effect on fleet emissions and I/M benefits by 1990. After additional data analysis and model development had been done, six technology groups were added, for a total of sixteen.

These same technology groups are used to represent light-duty trucks and medium-duty vehicles in the model, although the fractions of each group within a model year are obviously different from those for passenger cars.

The model has been written to accommodate a total of 20 technology groups, so that additional groups may be added when the data become available. Table IV-4 shows the emission control technology configurations for the groups used in the model.

C. Technology Fractions

Once emissions characteristics have been developed for each emissions control system technology group, the model combines the emissions data for the various technology groups to produce emissions data on a model year basis. The data are weighted by a technology fraction that represents the proportion of vehicles in that technology group in each model year.

Technology fractions for 1980 to 1985 model years were based on production data supplied by the ARB. Data for 1986 and later model year vehicles were taken from the projections of future emission control system technology made by Energy and Environmental Analysis,

Table IV-4

Technology Group Definitions

Technology Group	Model Years Included	Emission Control Configurations and Fuel Metering Systems
1.	Pre-1975	Without secondary air
2.	Pre-1975	With secondary air
3.	1975 and later	No catalyst
4.	1975-76	Oxidation catalyst, w/o secondary air
5.	1975 and later	Oxidation catalyst, with secondary air
6.	1977 and later	Oxidation catalyst, w/o secondary air
7.	1977-79	TBI/Carb, TWC
8.	1981 and later	TBI/Carb, single-bed TWC, 0.7 NOx
9.	1981 and later	TBI/Carb, dual-bed TWC, 0.7 NOx
10.	1977-80	MPFI, TWC
11.	1981 and later	MPFI, TWC, 0.7 NOx
12.	1981 and later	TBI/Carb, TWC, 0.4 NOx
13.	1981 and later	MPFI, TWC, 0.4 NOx
14.	1980	TBI/Carb, TWC
15.	1993 and later	TBI/Carb, TWC, 0.25 HC and 0.4 NOx
16.	1993 and later	MPFI, TWC, 0.25 HC and 0.4 NOx
17.	(Reserved)	
18.	(Reserved)	
19.	(Reserved)	
20.	(Reserved)	

Notes:
- TBI/Carb: Throttle-body injection or carburetor fuel metering system
- TWC: Three-way catalyst
- MPFI: Multi-point fuel injection system

Inc. (EEA) under contract to the ARB. However, no analysis could be found of California-specific technology fractions for pre-1980 model year vehicles.

Two sources of data were investigated: ARB surveillance data and a random selection of approximately 160,000 records from Smog Check Test Analyzer System (TAS) data tapes. It was believed that because surveillance program vehicle fleets are designed to be representative of the on-road vehicle fleet, the technology fractions found in these data would give a reasonably good indication of technology fractions in the on-road fleet. Although the TAS data constitute a much larger and arguably more complete data base for such an analysis, there were concerns about the ability of mechanics to correctly identify emission control systems. However, some who reviewed the technology fractions developed using surveillance data believed that the proportion of three-way catalyst (TWC) cars in the surveillance data was too high, and for that reason preferred the TAS data.

To check the accuracy of both sets of data, TWC technology fractions for 1980-83 model years developed using both surveillance and TAS data were compared with the production data from the EEA report. This comparison confirmed that the TAS data seriously underreport the incidence of TWC vehicles. For example, sales data indicate that 62% of 1980 model-year vehicles were equipped with TWC, while a one month sample of TAS data show that only 19% of MY 1980 vehicles were so equipped. In contrast, the surveillance data contain 72% model year 1980 TWC vehicles. For model year 1982, the sales data show approximately 81% TWC-equipped passenger cars, versus 65% for the TAS data and 85% for the surveillance data. Thus, while TWC vehicles may be somewhat overrepresented in the surveillance data, the underrepresentation in the TAS data seemed to be far more severe.

Therefore, the surveillance data were used as the basis for the pre-1980 model year technology fractions. The technology fractions used in the model are shown in Table IV-5.

Table IV-5

Technology Fractions by Model Year

Pre-1975 Model Years

Model Year	Without air	With air
1968	92%	8%
1969	94	6
1970	96	4
1971	79	21
1972	62	38
1973	53.5	46.5
1974	45	55

1975 and Later Model Years

Model Year	No cat	Ox cat, air	Ox cat, no air	TWC CARB/TBI	TWC MPFI
1975	10%	76%	14%	0%	0%
1976	12	72	16	0	0
1977	9	82	7	0	2
1978	5	80	10	3	1
1979	8	69	11	7	5
1980	0	26.5	11.4	49.4	12.7
1981		9.6	8.9	66.9	14.5
1982		18.1	0	66.8	15.1
1983		14.4		64.6	21.0
1984		1.5		76.0	22.5
1985		0		67.7	32.2
1986				59.6	40.4
1987				51.5	48.5
1988				43.8	56.3
1989				32.1	68.0
1990+				28.2	71.8

Note: 1968-79 fractions based on ARB Surveillance Programs 1-6. 1980+ fractions supplied by ARB staff (based on sales and EEA projections)

D. Determination of Emission Regimes

As discussed in Section III, two additional assumptions upon which the model is based are:

- emission performance of the vehicle; and
- effect of malfunctions.

These assumptions require that the vehicles be divided into emission regimes and that characteristic emission levels be assigned to each regime. The first step, however, was to determine how many regimes there should be. The constraints on this task were similar to those in the development of technology groups: regimes needed to be defined narrowly enough so that their emission levels were reasonably stable; however, the more regimes used, the less robust the sample of vehicles in each.

In EPA's original model using this approach, three regimes were used: normal, high and super. A vehicle was assigned to a regime by comparing both its HC and CO FTP emissions to specific gram/mile emission limits. The EPA model did not treat NOx emissions, and applied only to 1981 and later model year vehicles that were certified to the same HC and CO standards. Therefore, EPA used a single set of numerical standards to divide the fleet into regimes. (The only exception was that EPA separately accounted for vehicles that met 3.4 g/mi and 7.0 g/mi CO standards.)

The EPA staff's approach in defining emission regimes was to remove what they called "super-emitters", that is, vehicles with extremely high HC or CO emissions that could be statistically identified as outliers. Then all vehicles in the sample not judged to be outliers were classified as either "normal" or "high" emitters. This classification, based on analysis of I/M short test and FTP emissions data, divided the sample into vehicles tending to pass (normals) or tending to fail (highs) the I/M short test.

Under EPA's definition, "normal" vehicles could have emissions significantly higher than the certification standards but generally did not have major emission control system problems that would cause their emissions be high enough to fail an I/M test. "High" emitters were generally maladjusted or poorly maintained, with major problems or defects in their emission control systems. "Super" emitters had extraordinarily high emissions, due to complete loss of microprocessor control by newer vehicles or catalyst failure or carburetor malfunction in older model year vehicles.

In EPA's modeling approach, all vehicles with idle emissions in excess of the test cutpoint levels were considered to have failed the test, and it was assumed that their emissions were reduced to "normal" levels as a result of repair. Experience with the Smog Check program shows that this assumption is not applicable in California. The most obvious evidence is the fact that not all failed vehicles are repaired to levels that allow them to pass the I/M test: prior to 1990, fully 25% of the vehicles that fail the Smog Check program receive a waiver because complete repairs cannot be made within the program's cost limits.

Therefore, when the EPA modeling approach was adapted for use in the I/M Evaluation study, several modifications were made. One modification was to add a new emissions regime called "Moderate" between "Normal" and "High". This made the analysis more flexible and more representative of the California program, by allowing the modeling of vehicles that do not receive complete repairs. The other major change was to define the regimes by multiples of the FTP standards instead of numerical cutpoints. The use of multiples of the standards, rather than emission levels, allowed the same regime definition to apply to vehicles certified to different standards.

One basic premise of the emission regime concept is that specific, common types of defects occur in vehicles with similar emission control system technologies, and that these defects have similar effects on emissions. The result is that vehicles within an emission control technology group have emission levels that fall into discrete and identifiable groups. This premise was used as the basis for developing emission regimes for the CALIMFAC model.

In identifying emission regimes, the master data set was again divided into three model year groups, based on similarity of emission standards and control technology applicable to vehicles in those model years. The model year groups were used as a surrogate for the technology groups, because some technology groups contained too few vehicles to be analyzed separately. The model year groups are the same as those used in the tampering analysis:

- Pre-1975 model year vehicles
- 1975-79 model year vehicles
- 1980 and later model year vehicles

The regimes, their characteristics and definitions, and the analytical approach used to identify them, are described below. These definitions, and the corresponding statistical analyses, were performed independently for each pollutant.

Normals

The first group to be identified was the Normal group. Because the Normal group is the lowest emitting regime, vehicles in this regime that fail an I/M test and receive repairs can not reduce their emissions. Therefore, Normal vehicles were defined as vehicles that are likely to show no benefits from repair. These vehicles were identified by examining the change in emissions of individual vehicles after repair and identifying the group which, even under "perfect" repairs, showed an increase in average emissions after repair.

Table IV-6 shows, for each pollutant and model year-group, the multiple of the FTP standard below which an I/M-failing vehicle will have a net <u>increase</u> in emissions after repair.

Table IV-6

Breakpoints for Definition of Normal Emissions Regime

Pollutant	-- Multiples of the FTP Standard -- Pre-1975	1975-79	1980+
HC	0.5	1.0	1.0
CO	0.5	1.0	1.0
NOx	1.0	1.0	1.0

Based on this analysis, the breakpoint used in the model for determining normals was set at the FTP standard for all pollutants and model year groups. Vehicles with emissions equal to or less than the FTP standard for any pollutant were classified as "Normal" emitters for that pollutant.

<u>Supers</u>

The second group of vehicles to be identified was those with major emission control system malfunctions causing extremely high emissions. Previous I/M benefits analyses have suggested that the majority of I/M benefits come from identifying and repairing these vehicles. A cluster analysis was used to identify cutpoints at the highest end of the emissions distribution "tail", which defined vehicles that were clearly different from the bulk of the fleet.

<u>Number of Intermediate Categories</u>

Following the identification and removal from the data base of the normal and super-emitting vehicles, a cluster analysis was used to group remaining vehicles and to determine the number of identifiable subgroups between normals and supers for each pollutant and model year group. Three intermediate categories between normals and supers were found for each pollutant and model year group.

Breakpoints Between Moderates, Highs and Very Highs

The cluster analyses had indicated in a general sense where the breakpoints between the remaining regimes should be located. A further analysis of the characteristic emissions from the vehicles in each regime was done to identify breakpoints that would establish regimes for which there appeared to be little or no correlation between emissions and odometer. This approach would create regimes with very stable emissions, so that average emission levels could be defined for each regime. Once again, this approach is based on the model's premise that changes in emissions due to deterioration or repairs can be represented by changes in population of emissions regimes, as opposed to changes in the emission levels of vehicles within a regime.

The regimes used in the model are summarized in Table IV-7.

Table IV-7

Breakpoints Used to Define Emission Regimes

Regime	Multiples of the FTP Standard		
	HC	CO	NOx
Normal	≤1x	≤1x	≤1x
Moderate	1-2x	1-2x	1-2x
High	2-5x	2-6x	2-3x
Very High	5-9x	6-10x	3-4x
Super	>9x	>10x	>4x

E. Characteristic Emission Levels

Once the technology groups and emission regimes were defined, characteristic emission levels could be developed for each emission regime/technology group combination. As a method of further verifying that the appropriate regimes had been established, a linear regression analysis was done to determine whether there was any significant relationship between emissions and odometer within each regime.

The analysis showed that with rare exceptions, there was no significant relationship (at the 95% confidence level) for any but the normal regimes. Therefore, a simple arithmetic mean of the FTP and bag emissions of each pollutant was calculated for each of the four non-"Normal" emission regimes within each technology group. Linear regression equations for emissions as a function of odometer were calculated for the normal vehicles in each technology group. Where a Student's T-test for a normal regime showed a relationship between emissions and odometer that was significant at the 95% confidence level, the emission factor was expressed as a zero mile and deterioration rate function. Bag-specific and composite emission rates are shown by regime in Appendix B.

As discussed in Section IV.B, two technology groups (15 and 16) were included in the model to represent future technology vehicles (1993 and later model years). Since no emissions data were available for vehicles in these technology groups, emission rates were derived from the corresponding earlier model year groups (12 and 13).

The bag-specific data were calculated in the same manner as the composite emission rates. However, the emission data by bag for pre-1975 model year cars are not nearly as complete as the data for composite emission levels, so the means (and in some cases, regressions) for those vehicles are based on much smaller data samples. Therefore, the bag-specific emission factors for pre-1975 model year cars may be less reliable than the composite emission factors for those vehicles.

F. Emission Regime Population Functions

The population functions represent the change in the proportion of each particular technology in each emissions regime as a function of vehicle mileage. These functions were derived separately for each pollutant and technology group by computing the number of vehicles within each regime at 10,000 mile "bins" and developing a linear regression of the frequencies vs. mileage.

Where there were no vehicles in a particular emission regime within a mileage bin, that data value was considered to be zero percent, rather than a missing data point. This was done because it seemed to be the most appropriate means of representing the distribution of the data. To compensate for the fact that, especially for the technology groups that represent late model year vehicles, most of the vehicles have relatively low odometer readings, the percent of cars in each regime within each odometer bin was weighted by the percent of the technology group in that odometer bin before the regressions were calculated. This has the effect of giving more weight in the calculation to bins containing more data points, and which constitute a more valid sample.

The intercepts for the regressions were initially allowed to float, and were checked and adjusted as follows:

- If the intercept for a high, very high or super emitter category was greater than zero at zero miles, a new regression fixed through zero was computed. This was based on the belief that there are no high emitters in the population of new cars.

- If the intercept for high, very high or super emitters was less than zero, the regressions were used, although the model forces the regime size to remain at zero until the regression equation yields a positive value. This represents the case where malfunctions do not develop until a vehicle's mileage exceeds some level.

- The population of the moderate emitters was <u>not</u> fixed through zero. Because new vehicles must meet certification standards on average, not individually, some proportion of new vehicles will have emissions that exceed the certification standards and put them in the moderate category.

Although the regression of regime sizes was calculated simultaneously for the five regimes in each technology group, the percentages did not always sum to one. In some cases, the population of normal vehicles became negative at high (>80,000 miles) mileage. In addition, the treatment of the three higher emitting categories resulted in some negative population sizes for these regimes at early mileages. In all of these cases the population sizes are adjusted by the model. All negative population sizes are set to zero, and the population fractions are normalized to sum to 100% before being used in calculations. Sample population functions are shown graphically in Appendix C.

Special population functions were developed for Technology Groups 15 and 16, since there were no vehicles in the data base for these "new" technology vehicles. As in the case of the emissions rates for these groups, the population functions were derived from those for groups 12 and 13. However, based on directives from the CARB staff, the population functions for these technology groups were modified so that there would be no high, very high or super emitters present in the fleet for the first three years. This was done to reflect the ARB staff's belief that extended warranty requirements for the first three years of these vehicles' lives will encourage vehicle owners to seek repairs outside the I/M program.

G. Identification Rates

The identification rates indicate the percent of vehicles in a particular emission regime that will fail an I/M test with particular cutpoints, visual/functional component checks and level of mechanic performance. They were calculated based on how many of the vehicles in the regime failed either the emissions or the visual/functional check. The pass/fail determination for each part of the test was made as follows:

Emissions test: Emission cutpoints for three different I/M test types and two different stringency levels were provided by CARB staff. The emission cutpoints were provided by I/M category, and are shown in Appendix A. The emissions of each vehicle in the sample were compared to the appropriate cutpoint for each test type/standard stringency combination to determine whether the vehicle passed or failed each of the six individual tests. It was assumed that mechanic performance had no effect on the pass/fail result of the emissions test, due to the use of computerized emissions analyses.

Visual/functional check: Three levels of visual/functional checks (no visual/functional check; check AIR, EGR, O_2S and CAT; check AIR, EGR, O_2S, CAT, EVAP, crankcase and fillpipe) and three levels of mechanic performance (1984 program, SB 1997 program and enhanced training) were provided for evaluation by ARB staff. Specific components were inspected in each level of the visual/functional check, and only the state of inspected components was considered in making the pass/fail determination. For example, a vehicle with a tampered filler neck would fail the visual/functional portion of a test only if it included a filler-neck check.

The effect of mechanic performance on the results of the visual/functional check was taken from the analysis done in "Evaluation of the California Smog Check Program", prepared for the California I/M Review Committee by Sierra Research in April 1987.

According to that analysis, Smog Check mechanics are able to identify only between 17 and 67 percent of specific defects were detected by CARB mechanics.

The effect of enhanced mechanic performance and the use of on-board diagnostic (OBD) technology were based on ARB's OBD II staff report. For lack of any better data, enhanced mechanic performance was assumed to increase the identification rate for individual components by 50% on vehicles <u>not</u> equipped with OBD II systems (Technology Groups 1 through 14).

Initially, OBD I was assumed to provide half the improvement in identification rate provided by OBD II for the components monitored by OBD I (EGR and oxygen sensors). Using these assumptions, OBD I would improve the identification of EGR malfunctions from 25% to 35%. However, treating this improvement explicitly in the model would have required the addition of technology groups to represent vehicles equipped with OBD I. Because EGR malfunction rates in late-model vehicles are relatively low, it was decided that the small improvement in the identification rate did not justify the development of additional technology groups, so the effect of OBD I on EGR malfunction detection was neglected. Further, the identification rate for O_2 sensors in the Smog Check effectiveness study was found to be 67%, equivalent to the identification rate attributed by ARB to OBD II. Therefore, there would appear to be no enhancement of the O_2 sensor identification rate due to OBD I.

The accuracy of the visual/functional check in detecting malfunctioning components, under two levels of mechanic performance and with and without on-board diagnostic systems, is shown in Table IV-8.

Table IV-8

Accuracy of Visual/Functional Check
by Level of Mechanic Performance

Mechanic Performance	OBD Type	Type of Emission Control System						
		AIR	CAT	EVAP	EGR	LEAD	O2S	PCV
Original	None/OBD I	39%	44%	24%	25%	17%	67%	33%
	OBD II	45%[5]	44%[2]	36%[2]	45%[2]	N/A	67%[2]	33%[3]
Enhanced	None/OBD I	59%[4]	64%[4]	36%[4]	38%[4]	26%[4]	71%[4]	50%[4]
	OBD II	70%[5]	64%[1]	56%[1]	70%[1]	N/A	71%[1]	50%[4]

Notes:

1. Based on OBD II staff report; reflects high and moderate likelihood of identification. LEAD assumed to be equal to higher of CAT or O2S, since either test will identify lead poisoning.
2. Based on higher of current mechanic performance and OBD II staff report estimates for high likelihood identification. LEAD assumed to be higher of CAT or O2S, since either test will identify lead poisoning.
3. Not monitored by this type of OBD.
4. Enhanced mechanic performance assumed to increase identification rates by 50%, up to the level achieved with OBD II and enhanced performance.
5. Since no data are available on the effectiveness of OBD II systems for air injection, and given the technical similarity between the detection of EGR and AIR flows, use EGR values.

To determine a vehicle's likelihood of failing a particular visual/functional inspection under a specific level of mechanic performance, the probability of the vehicle's passing the inspection was calculated as follows:

$$P_p = (1-P_{f1})*(1-P_{f2})*...*(1-P_{fn})$$

and

$$P_f = 1-P_p$$

where

P_p = probability that the vehicle will pass the visual/functional inspection

P_f = probability that the vehicle will fail the visual/functional inspection

P_{fn} = probability that the mechanic will identify defective component n (from Table 6)

If the vehicle failed the tailpipe portion of the test for any pollutant, the vehicle was assigned a value of 1 for the probability of failing, regardless of the results of its visual/functional inspection.

The likelihood that a vehicle in a particular technology group and emissions regime will fail a particular combination of tailpipe standards and visual/functional checks was then calculated by adding up the values of P_f for each vehicle in that tech group and regime, and dividing that total by the number of vehicles in that group. These calculations are performed outside the model for each technology group, emissions regime, pollutant, tailpipe standards and visual/functional checks to develop the identification rate matrix used by the model. For example, consider a sample of four vehicles in Tech Group 9 that are high emitters for CO.

Following is a sample calculation that illustrates the determination of the percentage of CO-high emitters in Tech Group 9 that would be identified as failing that particular I/M program (combination of emission test type, standard stringency, visual/functional check and mechanic performance):

Vehicle Number	Probability of Failure
1	1.0 (failed tailpipe test)
2	0.75 (EGR and AIR malfunctions, passed tailpipe test)
3	0.38 (EGR malfunction, passed tailpipe test)
4	0.0 (no defects, passed tailpipe test)

$$\text{Percentage of sample failing test} = \frac{(1.0 + 0.75 + 0.38 + 0.0)}{4}$$

$$= 0.53$$

The vehicle is considered to have failed for all pollutants if it failed the emissions test for any one pollutant, or failed the visual/functional checks. This was done to account for the effect on emissions of "incidental" repairs. These incidental repairs, which occur when repairs reduce emissions of a pollutant other than that for which the vehicle failed inspection, are thought to have produced the small NOx benefits found in the I/M Evaluation program, despite the lack of a NOx emissions test.

H. Correction Efficiency

Correction efficiencies are used in the model to describe the movement of failed vehicles after repair. The effectiveness of a vehicle's repair is determined by the mechanic's ability to correctly repair a vehicle and by the limits on the costs of repairs that must be undertaken to bring a vehicle into compliance. The impact of mechanic performance and repair cost limits on the effectiveness of repair were derived from Table 11-20 of "Evaluation of the California Smog Check Program", reproduced here as Table IV-9.

Table IV-9.

Effect of Repair Cost Ceiling on Failed Vehicles With Obvious Defects

	Pre-75 Models	75-79 Models	1980 and Later Models	Overall
Repaired @ Smog Check	69%	64%	46%	59%
Should Have Been Repaired Under $50 Cost Ceiling	20%	16%	20%	19%
Additional Repairs Possible w/ $150-200 Cost Ceiling	11%	16%	18%	15%
Additional Repairs Possible w/ $400-500 Cost Ceiling	0%	4%	16%	7%
Totals	100%	100%	100%	100%

The effectiveness of repairs under the $50 repair cost ceiling with the current level of mechanic performance was taken from the first line of the table. The factors shown there were used to adjust the effectiveness of the CARB mechanic repairs. The effectiveness of repairs under the $50 repair cost ceiling with the highest level of mechanic performance was taken from the sum of the first and second lines of the table. The intermediate level of mechanic performance was estimated by interpolating between the two.

The effectiveness of repairs under higher cost ceilings (lines 3 and 4 of the table) was used to estimate the increased effectiveness for options 2 and 3 of the model. For example, under option 2, the cost limit for 1980-89 model year vehicles is raised to $175. This corresponds approximately to line 3 of the table for the highest level of mechanic performance. To estimate the repair effectiveness under option 2 for the original level of mechanic performance, the repairs possible under the higher cost ceiling were adjusted by the ratio of the percent of the vehicles repaired under the original program to the percent that should have been repaired under the $50 limit.

For example, for 1980-89 model vehicles:

original mech. performance, $50 ceiling: 46% effective
highest mech. performance, $50 ceiling: 46% + 20%
= 66% effective
highest mech. performance, $175 ceiling: 46% + 20% + 18%
= 84% effective
original mech. performance, $175 ceiling: (84%/66%) x 46%
= 59% effective

Again, the intermediate level of mechanic performance was estimated by interpolation.

Options 2 and 3 apply a $50 cost limit to pre-1972 model year vehicles and a $90 limit to 1972-74 model year vehicles. This scenario does not correspond exactly to any case analyzed in Table 11-20.

Therefore, it was assumed that this limit would produce about half the benefits that the $150-200 limit would produce for these older cars. The factors used to adjust correction efficiencies for mechanic performance and repair cost limits are shown in Table IV-10.

Table IV-10

Adjustment Factors: Mechanic Performance and Repair Cost Limits

Model Year Group	Cost Limit	--- Mechanic Performance --- 1988 Level	1990 Level	Enhanced Training
Option 1				
Pre-1975	$ 50	.69	.79	.89
1975-79	50	.64	.72	.80
1980+	50	.46	.56	.66
Option 2				
Pre-1972	$ 50	.69	.79	.89
1972-74	90	.73	.83	.94
1975-79	125	.70	.79	.88
1980-89	175	.59	.72	.84
1990+	300	.64	.78	.92
Option 3				
Pre-1975	no limit	.78	.89	1.00
1975-79	no limit	.80	.90	1.00
1980+	no limit	.70	.85	1.00

The effectiveness of the best possible repair under the program was determined by examining emission levels for failed vehicles after the last ARB repair. The vehicles were assigned to post-repair emission regimes based on these after-repair emissions. Thus, a matrix of before- and after-repair emission regimes could be developed that showed the percent of vehicles in each post-repair regime based on their pre-repair regime. For example, consider the following set of before- and after-repair emission results:

Before-Repair	After-Repair
50 Normals	49 Normals, 1 Moderate
25 Moderates	20 Normals, 5 Moderates
10 Highs	5 Normals, 3 Moderates, 1 High, 1 Very High
5 Very Highs	2 Normals, 2 Moderates, 1 Very High
2 Supers	1 Normal, 1 High

These results would produce the correction efficiency matrix shown in Table IV-11.

Table IV-11

Sample Correction Efficiency Matrix: "Perfect" Repairs

Before-Repair	----- After-Repair Regime -----				
Regime	Normal	Moderate	High	Very High	Super
Normal	0.98	0.02	0	0	0
Moderate	0.80	0.20	0	0	0
High	0.50	0.30	0.10	0.10	0
Very High	0.40	0.40	0	0.20	0
Super	0.50	0	0.50	0	0

The determination of after-repair emission levels, and assignment to after-repair emission regimes, was performed separately for each pollutant. Therefore, in the case where the repair of a super HC emitter had created a high NOx emitter in the data base used for developing correction efficiencies, the data analysis would reflect that as one of the HC supers moving to a lower emitting regime after repair, and one of the low NOx emitters moving to a higher regime after repair.

The percentage factors used to account for the effects of mechanic performance and repair cost limits were applied to reduce the percentage of vehicles moving to lower-emitting regimes as a result of repair. The number of vehicles moving to higher-emitting regimes was not changed, based on experience gained in the evaluation of Bureau of Automotive Repair (BAR) enforcement practices. Telephone interviews with BAR mechanics indicated that if a mechanic is not familiar with a particular vehicle model, he or she refers the owner to another repair shop rather than trying to repair the vehicle. This suggests that a lower level of mechanic performance reduces the effectiveness of repairs in lowering vehicle emissions, but does not increase the incidence of cars with higher emissions.

To illustrate the application of these "adjustment factors", assume that the sample matrix shown in Table IV-11 was developed for a technology group containing 1980 and later model year cars. An adjustment factor of 0.46, corresponding to Repair Cost Limit Option 1 ($50 limit for all model years) and less-stringent mechanic licensing requirements for 1980 and later model year vehicles, would be used to adjust the correction efficiencies to reflect the 1988 program. The adjustment factor would be applied to the percent of the after-repair fleet that had moved to a lower-emitting regime. The vehicles in the fleet that are not repaired, because of cost and mechanic performance limitations, would stay in their pre-repair regime. The results of the adjustment are shown in Table IV-12.

Table IV-12

Sample Correction Efficiency Matrix
Adjusted to Reflect $50 Cost Limit and
Current Level of Mechanic Performance

Before-Repair Regime	----- After-Repair Regime ----- Normal	Moderate	High	Very High	Super
Normal	0.98	0.02	0	0	0
Moderate	0.37	0.63	0	0	0
High	0.23	0.14	0.53	0.10	0
Very High	0.18	0.18	0	0.64	0
Super	0.23	0	0.23	0	0.54

I. VMT and Travel Fractions

Inspection/maintenance programs are run on an annual or biennial basis, so all model calculations are done at one-year intervals. Emissions, however, are related to vehicle mileage, so a relationship has been established between vehicle age in years and odometer reading in miles.

The CARB has adopted the EPA-developed relationship between vehicle age and odometer reading for 20 years of a vehicle's life. Because the ARB staff uses 25 years of vehicle miles travelled (VMT) data in developing emission factors, they extended the data through 25 years by assuming that VMT remains constant for years 19 through 25 of the vehicle's life. Therefore, the odometer reading increases by the same number of miles each year for years 19 through 25.

The VMT data developed by EPA are based on national vehicle data. Sierra Research had analyzed VMT data collected under the Smog Check evaluation program in mid- to late-1987, and developed another age vs. mileage relationship, which was believed to represent current

California vehicle driving patterns more accurately. The VMT data collected under the Smog Check program were adjusted to correct for data entries, as follows:

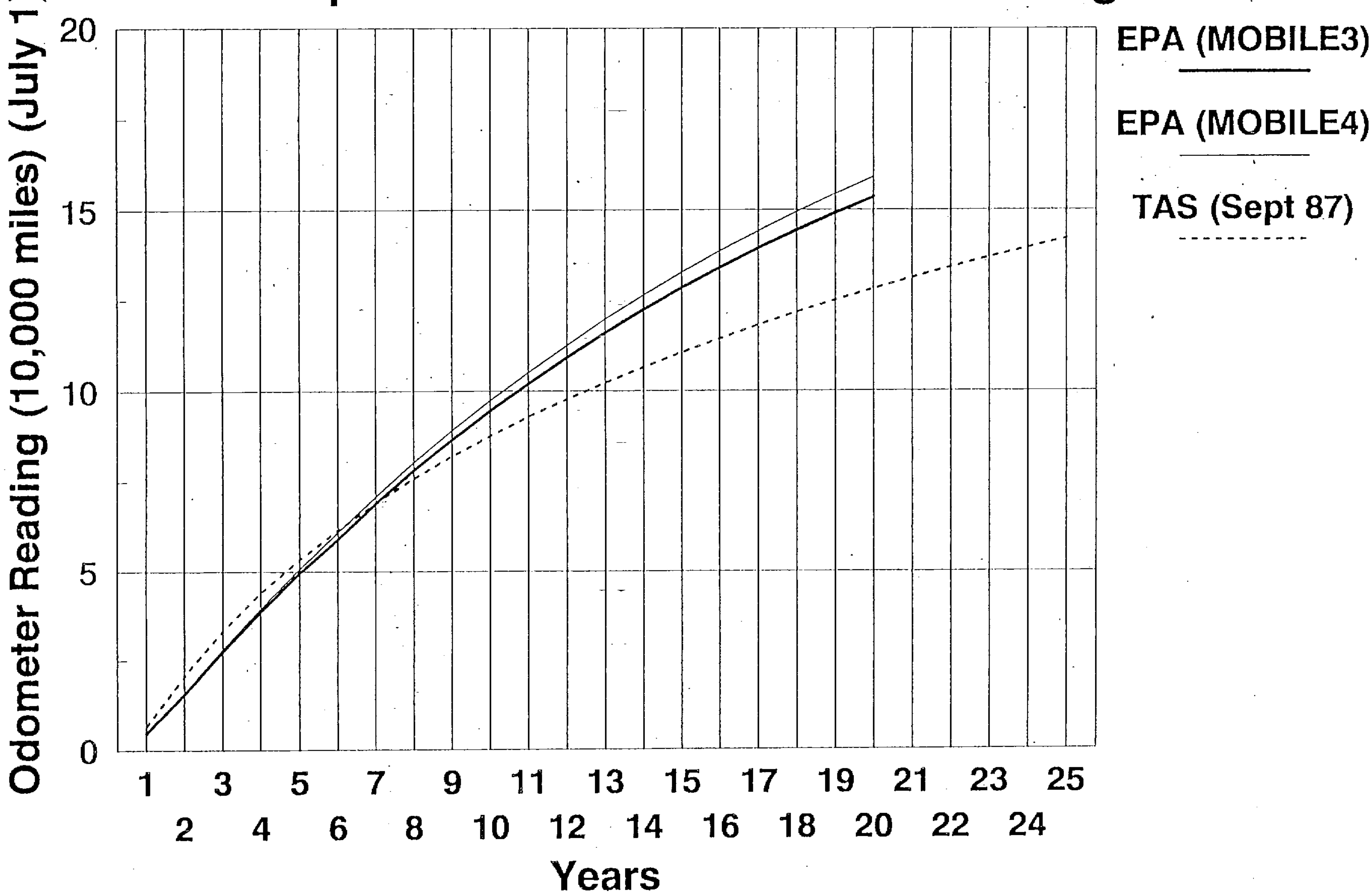
- Determine vehicle's age by subtracting vehicle's model year from test date. (See Appendix D for more detail.)
- If entered mileage is greater than 50,000 times the vehicle's age in years (indicating that the vehicle had accumulated over 50,000 miles per year), divide the odometer reading by ten. This reflects the assumption that the mechanic who entered the data read tenths of miles as miles, so that the odometer reading was off by a factor of ten. This adjustment was made to approximately 10% of the records.
- If the vehicle is more than two years old and its entered mileage is less than 4000 times its age in years, assume that the odometer has rolled over and add 100,000 to the odometer reading. This adjustment was made to approximately 16% of the records.
- If the vehicle has more that 300,000 miles on the odometer, remove it from the sample. This eliminated less that 0.5% of the vehicles from the sample.

The adjusted data sample was then subjected to nonlinear regression techniques to derive the best fit curve to the data. Of the tested regression curves (exponential, logarithmic, power and second-order polynomial), the logarithmic relationship between vehicle age and odometer reading was found to have the highest correlation coefficient.

For consistency reasons, the CARB staff elected to use the EPA MOBILE4 VMT and travel fraction data in the CALIMFAC model, however. VMT fractions are used to weight the emissions from vehicles of each model year before the emissions are combined to calculate emissions by calendar year. Figure IV-1 illustrates the differences between the fleet cumulative mileage derived from ARB and California data. The

Figure IV-1

Comparison of Cumulative Fleet Mileage



California data developed by Sierra Research show that more miles are driven each year by newer model year cars, and that fewer miles are driven by older cars, than is assumed when the MOBILE4 data are used. As a result, due to the use of the MOBILE4 data the model weights older cars more heavily than should be the case, resulting in a slight overestimate of fleet emissions.

J. Behavior of Post-Repair Vehicles

As discussed previously, under this modeling approach vehicles change their emission levels as a result of deterioration or repair by moving to a different vehicle regime. In doing so, it is assumed that they take on all the characteristics of the other vehicles in that regime. In making this assumption, any differences between the vehicles that deteriorated to a regime and the vehicles that were repaired to a regime are ignored. There are two factors that are not being accounted for and which may affect this assumption.

Tampering deterrence: EPA staff believe that the presence of an I/M program deters tampering, either by discouraging initial tampering, for fear of detection, or by preventing re-tampering after the I/M program causes initial tampering to be repaired. This effect would tend to slow the migration of vehicles into higher-emitting categories due to tampering and thus to reduce growth rates for high-emitting vehicles.

Accelerated deterioration of repaired vehicles Some analysts believe that a defective vehicle that has been repaired to a lower-emitting regime has a greater likelihood of developing increased emissions than a vehicle that has deteriorated to that regime. This accelerated deterioration could result from such things as a remaining defect that was not repaired and would cause the original defect to reoccur, or a pattern of owner neglect or abuse that caused the original defect and is not affected by the repair. However, the repaired vehicles could also exhibit decelerated deterioration due to the replacement of tampered or defective parts.

Sierra Research recently completed an analysis of I/M Evaluation program "recapture" vehicles. These are vehicles that were tested and repaired during the I/M Evaluation Program, then were returned to the test laboratory after approximately six months in customer service. This analysis showed that, with the exception of pre-1975 model year cars, post-repair emissions deteriorate at essentially the same rate as pre-repair emissions in the tested vehicles. Since pre-1975 model year vehicles have a steadily decreasing impact on fleet emissions in later years, this assumption is a reasonable one for all vehicles.

V. Results

A. Baseline Emission Factors

Baseline emission factors have been developed for model year 1965 to 2004 gasoline-powered passenger cars using the CALIMFAC model. The CALIMFAC-predicted emission factors, along with EMFAC7D and MOBILE4-based factors, are shown in Figure V-1 for the 1994 model year. The CALIMFAC factors reflect CARB's election to use a two-line regression; the EMFAC7D factors are based on a CARB staff report for the 0.25/3.4 g/mi HC and CO standards; and the MOBILE4-based factors are adjusted for the lower California certification standards and future regulations, using the techniques described in a report prepared for the Northeast States for Coordinated Air Use Management in 1989.

The figures show that the California factors continue to predict lower emission rates for in-use vehicles than do the MOBILE4-based estimates. Part of this can be explained by CARB's assumptions regarding the performance of "new technology" vehicles; however, even without those assumptions, CALIMFAC would predict lower emissions than MOBILE4 for the same emission standards.

Although no detailed analysis of the differences have been performed, one key area to check is the treatment of tampering. In the CALIMFAC model, tampered vehicles are handled implicitly. That is, the number of tampered and malperforming vehicles in the data base used to develop the modeling data was adjusted to represent as accurately as possible the component-specific tampering rates observed in the on-road fleet, and those vehicles are included in the emission factor analysis. In the MOBILE4 model, the effect of tampered vehicles on emissions is calculated separately as an offset to the emission factors derived for non-tampered vehicles. The emission levels and deterioration rates developed using this method for tampered vehicles are based on extremely small data sets, and a large number of assumptions are required. It is believed that the implicit treatment of tampered vehicles used by CALIMFAC more accurately accounts for emissions from these vehicles.

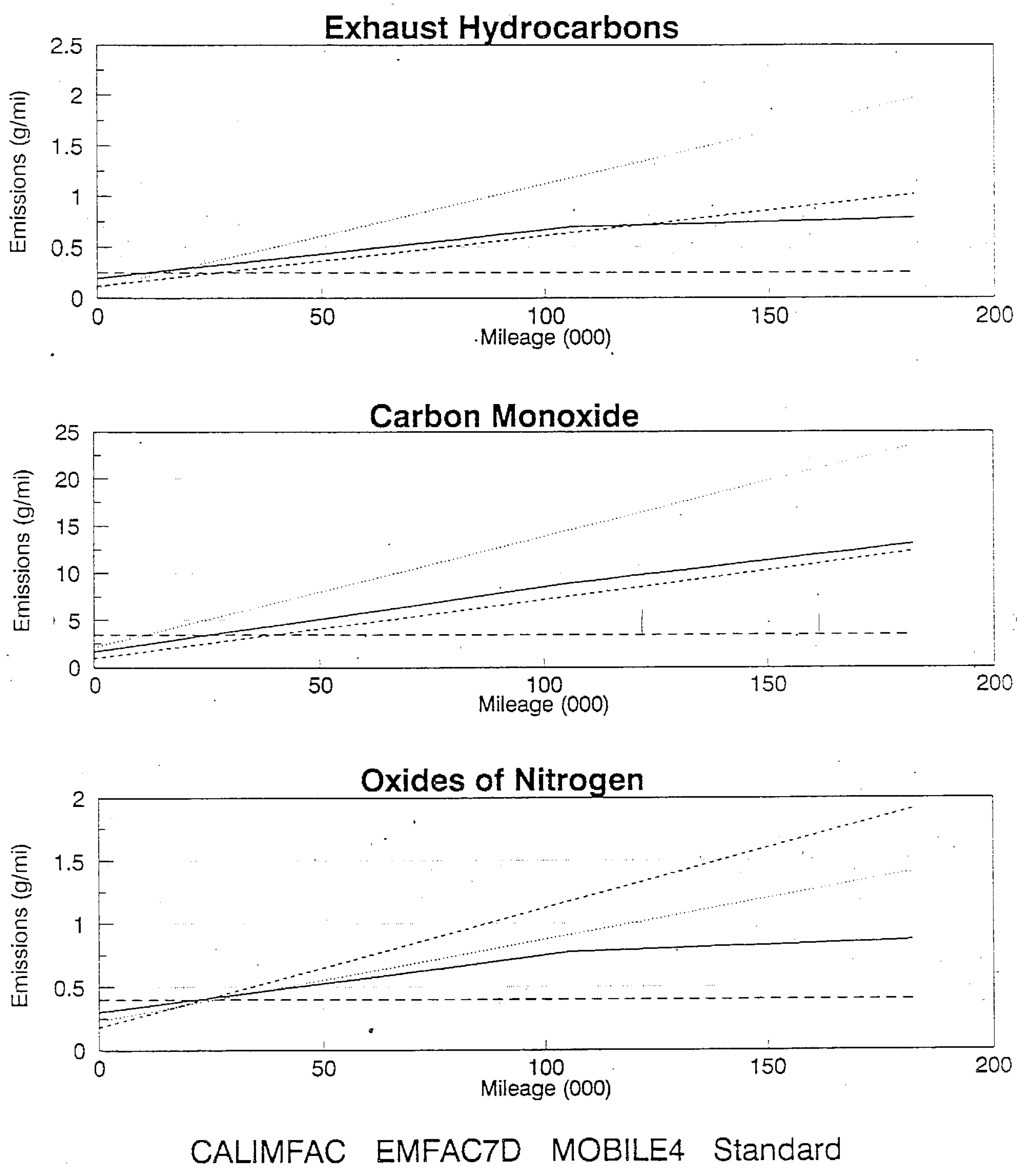
B. I/M Benefits

1. Uncertainty in Model Projections

While the CALIMFAC model predictions regarding program benefits are based on extensive amounts of data, most of these data are from the in-use surveillance programs and the 1984 I/M evaluation program. These data are most reliable for developing emission factors for vehicles through the 1986 model years, and for determining the benefits of the 1984 I/M program. Predicting the emissions characteristics of future model year vehicles requires the use of engineering judgement and other assumptions regarding technology, regulations, enforcement, and vehicle use and other owner practices. Simulation of I/M program options beyond those that are part of the 1984 program requires assumptions about all of these factors as well as the influence of mechanic training and higher repair cost ceilings, among other things. Therefore, the uncertainty in the model predictions for these scenarios is greater than that of the 1984 I/M program predictions.

Figure V-1

Predicted Emission Rates
1994 Model Year Vehicles



Factors include tampering, but do not reflect I/M program benefits.

2. Baseline Program

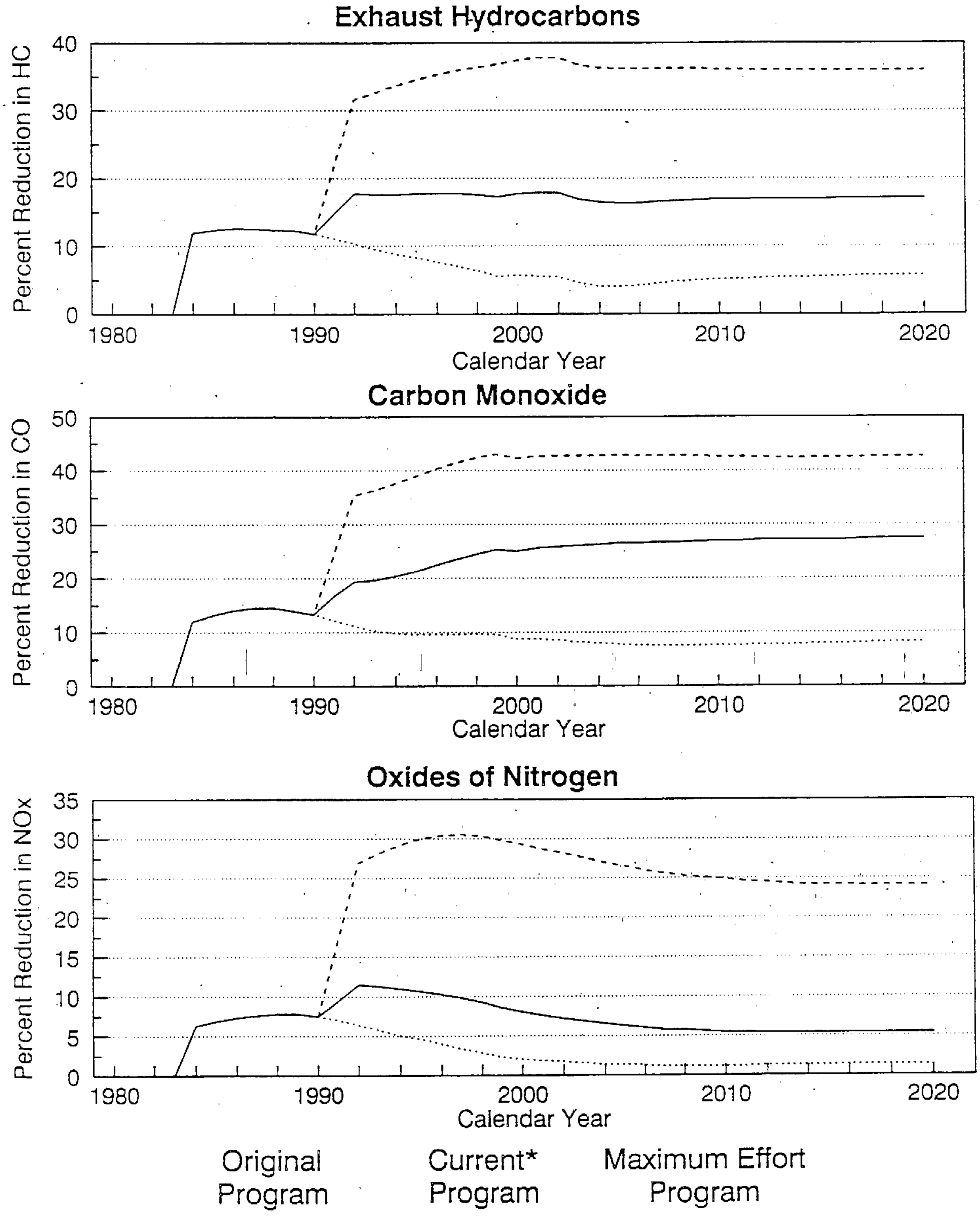
CALIMFAC projections of the benefits of California's past (1984) and current (SB 1997) I/M programs are shown in Figure V-2. Under the current smog check program, program benefits for HC are predicted to peak around 2001-02, with reductions of approximately 18 percent, and then to gradually decrease to 17% over the next fifteen years. CO benefits are predicted to increase slowly throughout the period modeled, leveling out at slightly over 27% around 2020. The model predicts NOx emission benefits of nearly 12% in the early 1990s for the current program. Although the idle test is not effective at detecting NOx emission failures, the benefits are associated with "incidental" repairs which occur when the vehicles have failed other portions of the inspection or have failed the visual/functional check or the idle test for other pollutants.

In evaluating the CALIMFAC predictions of Smog Check program benefits in 1995 and later years, it is important to note that the emissions calculations for these years are dominated by the behavior of 1985 and later model year vehicles. However, because very few vehicles from these model years were available for testing, little actual emissions data from these vehicles could be used in the development of the model. Therefore, estimates of emissions from these vehicles, especially at high mileage, were based on engineering judgment regarding the development of emission control system technology and the in-use performance of those systems.

As discussed briefly in Section III, the regressions used to calculate with- and without I/M emission factors are based on all of the data points from the sequentially-implemented programs. While the change in benefits between sequential programs should appear as a step function (similar to that occurring at the start of the original program in 1984), the regression smooths the step, with the result that in the model output, the benefits of an improved program starting in 1990 appear in the regression line as early as 1984. To emphasize

Figure V-2

CALIMFAC Sensitivity Analysis
Original, Current and Maximum Effort Programs



* Original program in effect 1984 to 1990;
SB 1997 effective starting 1990

that the sensitivity analyses have been performed to evaluate the impacts of program changes starting in 1990 and fully implemented in 1992, the step function at the point at which the program changes occur is shown in each graph.

3. Maximum Effort Smog Check Program

A second analysis was performed of the potential benefits of a "maximum effort" Smog Check program, to incorporate program options that would optimize the effectiveness of the program. Following is a list of the options incorporated in this analysis:

Inspection Frequency:	ANNUAL
Change of Ownership Rate:	17.00%
Inspection Test Type:	All steady-state loaded mode
Visual/Functional Checks:	BEST (Check AIR, EGR, O2S, CAT, EVAP, Crankcase, Fillpipe)
Emission Standards Stringency:	More stringent
Repair Cost Limits:	No cost limits
Mechanic Performance:	Enhanced training requirements
Model Years Included:	
Max. Age for Inspected Vehicles:	20
Earliest Model Year in Program:	1965
Vehicle Exemptions:	
Years Before Inspection for New Cars:	0
Inspection-free Year After Pass?	NO

CALIMFAC predicts that these program changes would significantly improve the effectiveness of the Smog Check program. The benefits of the optimized program are also shown in Figure V-2. HC emissions benefits are projected to more than double, increasing to nearly 38%, by 2001 if these program changes were implemented in 1990. CO benefits would increase to approximately 42% by 2012. The most dramatic improvement is seen in NOx emissions benefits. These benefits would nearly triple by the mid-1990s, to 30%. Moreover, instead of dropping to 5%, as they are predicted to do under the current program, they would remain high, declining only to 24% by 2020.

C. I/M Benefits Sensitivity Analysis

The model was subjected to a number of sensitivity analyses to evaluate the effect of various input parameters on the calculated I/M benefits. In each case, a single input parameter is changed beginning in 1990 and is varied through its entire range, and the predicted I/M program benefits are compared to those from the program modeled when the default program options are used. The effects on benefits of the various parameters are shown in Figures V-3 through V-12, and are discussed below.

1. Regression Type

At the direction of CARB staff, the weighted regression equations are performed for two straight lines with a "flex" point at which the slope changes. Two alternative regression techniques are available as user options: single straight line, and power curve. The fit of these alternative regression lines to the calculated emission data points is shown for exhaust hydrocarbon emissions for the 1980 and 1990 model years in Figure V-3.

Because I/M program benefits are calculated as the difference between points on the with- and without-I/M emission factor regression lines, the choice of regression techniques affects the calculated I/M benefits. The impact of regression types on I/M benefits calculated for the baseline program is shown for each pollutant in Figure V-4. Although the flexpoint regression appears to fit the data points best for the 1980 exhaust hydrocarbons, the abrupt change in slope at the flexpoint (which occurs at different mileage points for different model years and pollutants, since the point is determined dynamically) produces erratic behavior of the predicted benefits for HC and CO

Figure V-3

CALIMFAC Sensitivity Analysis
Regression Type

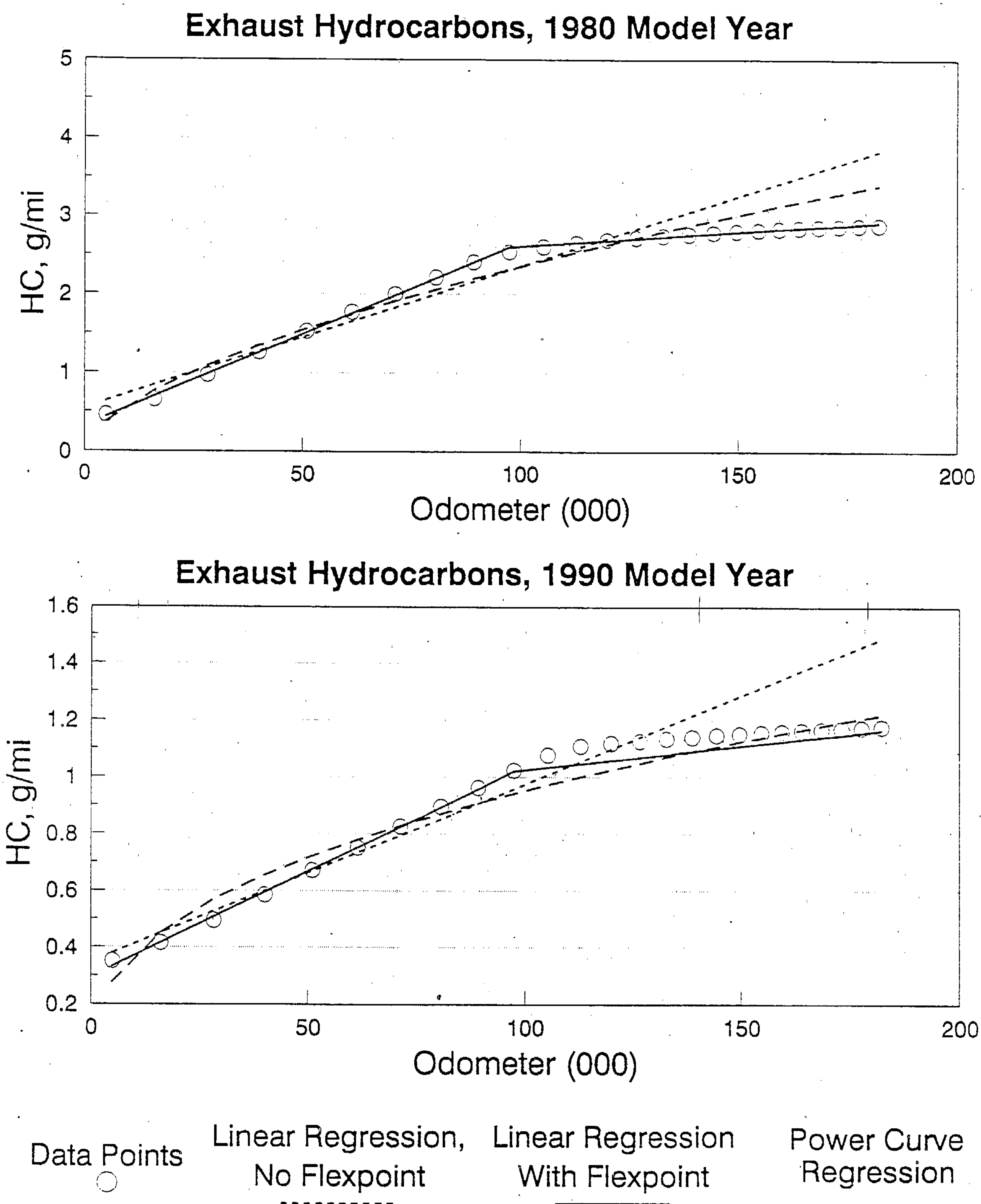
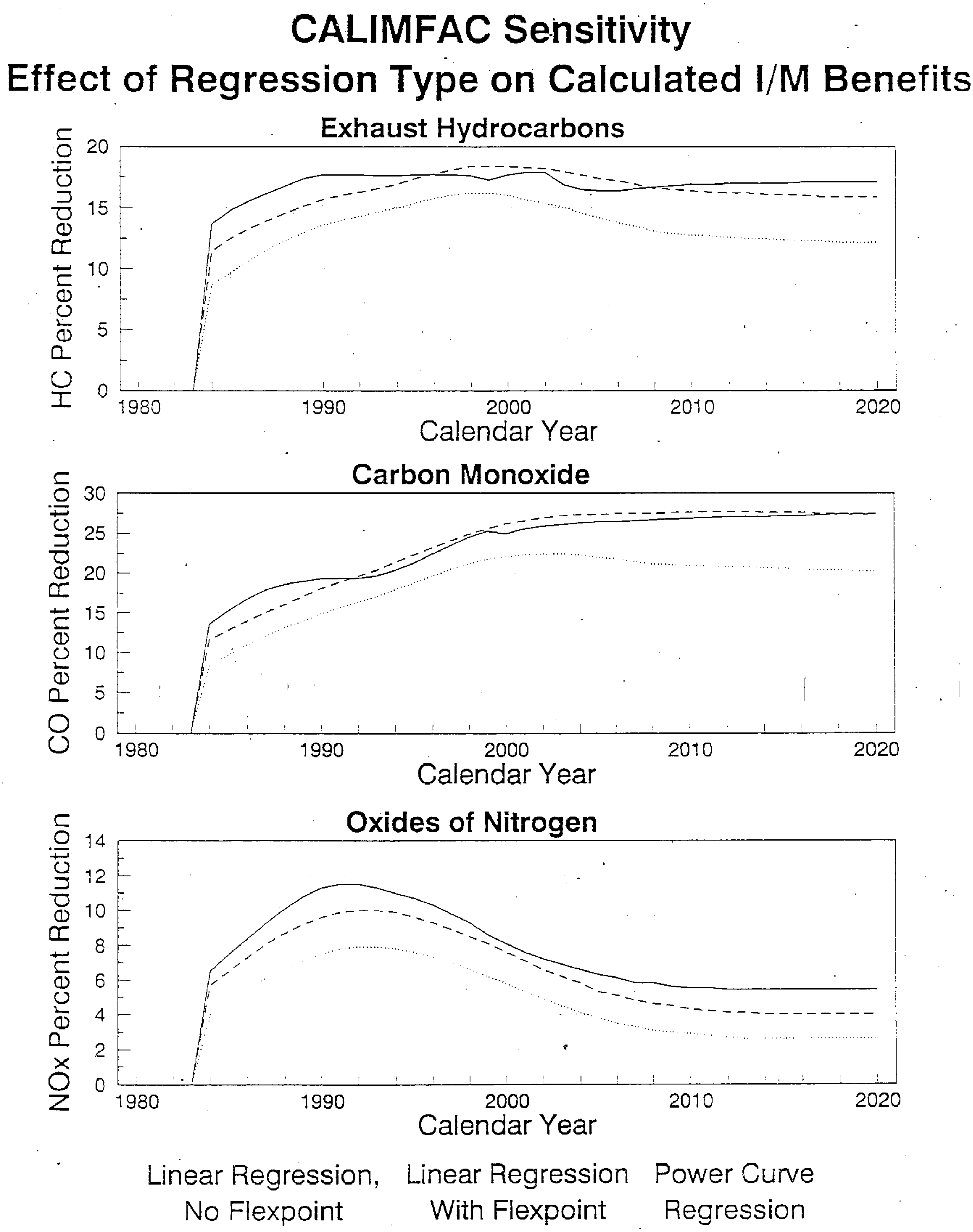


Figure V-4


CALIMFAC Sensitivity
Effect of Regression Type on Calculated I/M Benefits
Exhaust Hydrocarbons
HC Percent Reduction
20
15
10
5
0
1980
1990
2000
2010
2020
Calendar Year
Carbon Monoxide
CO Percent Reduction
30
25
20
15
10
5
0
1980
1990
2000
2010
2020
Calendar Year
Oxides of Nitrogen
NOx Percent Reduction
14
12
10
8
6
4
2
0
1980
1990
2000
2010
2020
Calendar Year
Linear Regression, No Flexpoint
Linear Regression With Flexpoint
Power Curve Regression

benefits between 1990 and about 2008. The two linear regression techniques produce generally higher predicted benefits than does the power curve regression.

2. Inspection Frequency

The default program has a biennial inspection with a 17% annual change of ownership. Two alternative inspection frequencies were modeled: an annual program, and a biennial program in which no change of ownership inspection is required. The results are shown in Figures V-5.

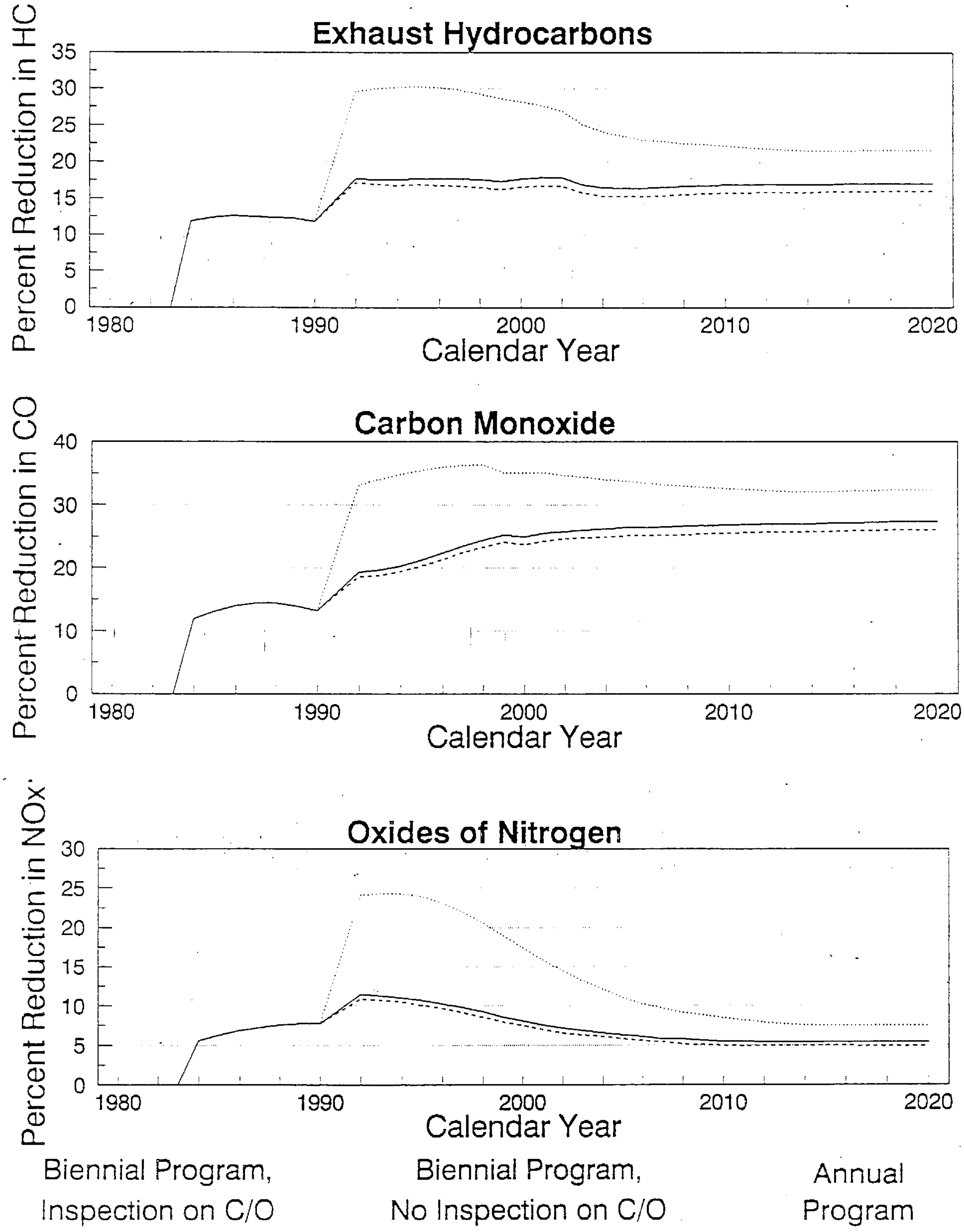
Eliminating the change of ownership inspection requirement is projected to reduce peak HC benefits by less than 6 percent (from approximately 18% to approximately 17% in 1995) and peak CO benefits by approximately 4 percent (from 27% to 26% in 2020). NOx benefits would be reduced by 3 to 10 percent during the period modeled.

The model is highly sensitive to inspection frequency; therefore, implementation of an annual program is predicted to increase program benefits significantly. Hydrocarbon benefits are predicted to improve from approximately 18% to over 30%, an increase of 67 percent. Carbon monoxide benefits show a similar improvement in the earlier years, going from 24% to 36% in 1995, with a smaller improvement (from 27% to 32%) in 2010. NOx benefits show the most dramatic improvement in the 1990s, more than doubling from 12% to over 24%.

The principal reason for these benefits is the increased likelihood of detecting high emitting vehicles that are currently "missed" due to poor mechanic performance.

Figure V-5

CALIMFAC Sensitivity Analysis Frequency of Inspection



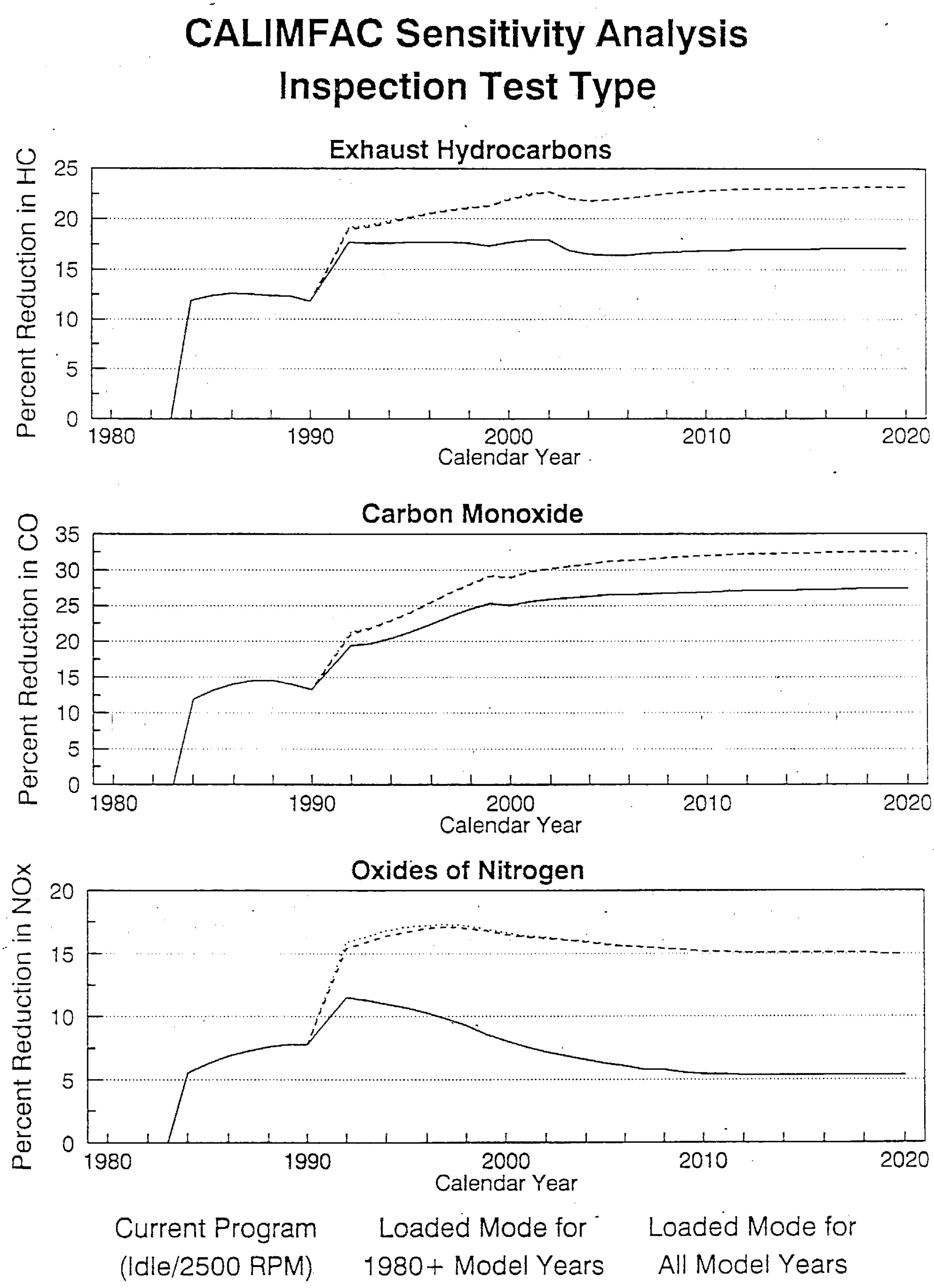
3. Inspection Test Type

Inspection benefits are also highly sensitive to inspection test type. Under a steady-state loaded mode test, loaded mode test results are compared to test cutpoints for all three pollutants (HC, CO and NOx) in addition to the two-pollutant, idle mode test. Therefore, more malfunctioning vehicles can be detected and failure rates are greater. As a result, more vehicles are repaired and benefits are higher. Therefore, implementing a steady-state loaded mode inspection test is also predicted to substantially improve program benefits for all three pollutants (see Figure V-6). The application of a steady-state loaded-mode test to all vehicles produces the earliest and largest reductions in NOx emissions, with a 35% improvement in the mid-1990s (increasing benefits from 11% to 17%) and nearly a 300% improvement by 2010 (from 5.4% to 15.2%). If the loaded mode inspection is applied only to 1980 and later model year vehicles, the short-term improvement is slightly less, but by 2000 the benefits associated with pre-1980 vehicles, which are inspected using the less effective idle test, are relatively insignificant.

The effects on HC and CO emissions are similar. The steady-state test improves HC benefits by 35% and CO benefits by approximately 19% by 2010. The all steady-state inspection test is not discernibly more effective for HC and CO emissions than a program under which the pre-1980 model year vehicles are subjected to an idle test.

Although the model predicts large emission benefits with the implementation of a loaded mode test, the ARB staff has indicated that loaded mode testing is not cost effective in light of other measures taken by ARB.

Figure V-6


CALIMFAC Sensitivity Analysis
Inspection Test Type
Exhaust Hydrocarbons
Percent Reduction in HC
25
20
15
10
5
0
1980
1990
2000
2010
2020
Calendar Year
Carbon Monoxide
Percent Reduction in CO
35
30
25
20
15
10
5
0
1980
1990
2000
2010
2020
Calendar Year
Oxides of Nitrogen
Percent Reduction in NOx
20
15
10
5
0
1980
1990
2000
2010
2020
Calendar Year
Current Program
(Idle/2500 RPM)
Loaded Mode for
1980+ Model Years
Loaded Mode for
All Model Years

4. Emission Standard Stringency

Increasing the emission standard stringency has a small but significant effect on benefits of the baseline program. Under this test scenario, the idle emissions of each vehicle are compared with stricter tailpipe standards to make the pass/fail determination. Because failure rates are slightly higher with more stringent standards, benefits are also higher. Hydrocarbon benefits increase by about 7 percent, from 17.7 to 19.1 percent. CO benefits increase by about 11 percent. NOx benefits increase much more markedly, from about 13 percent in the mid-1990s to about 50% by 2020. The NOx benefits are due to the incidental benefits of repairing the additional vehicles failed under the stricter standards. These results are shown in Figure V-7.

It should be noted that this analysis looked only at the effect of increasing stringency of the emission standards used in the idle test. Stricter cutpoints may have a greater effect on benefits when other types of tests are used.

5. Repair Cost Limits

An examination of various repair cost limits on the predicted benefits from I/M shows that the model is quite sensitive to that parameter. Increasing repair cost limits beyond the $50 limit for all model years in the original program has had a very beneficial effect on HC and CO benefits from the baseline program. Additional, smaller increases could be achieved by removing the cost limit on repairs. These effects are shown in Figure V-8.

The model shows that removing all cost limits improves program benefits only marginally. This is due to the fact that the data used in adjusting the correction efficiencies for repair cost limits contained no analysis of the effect of increasing the repair cost

Figure V-7

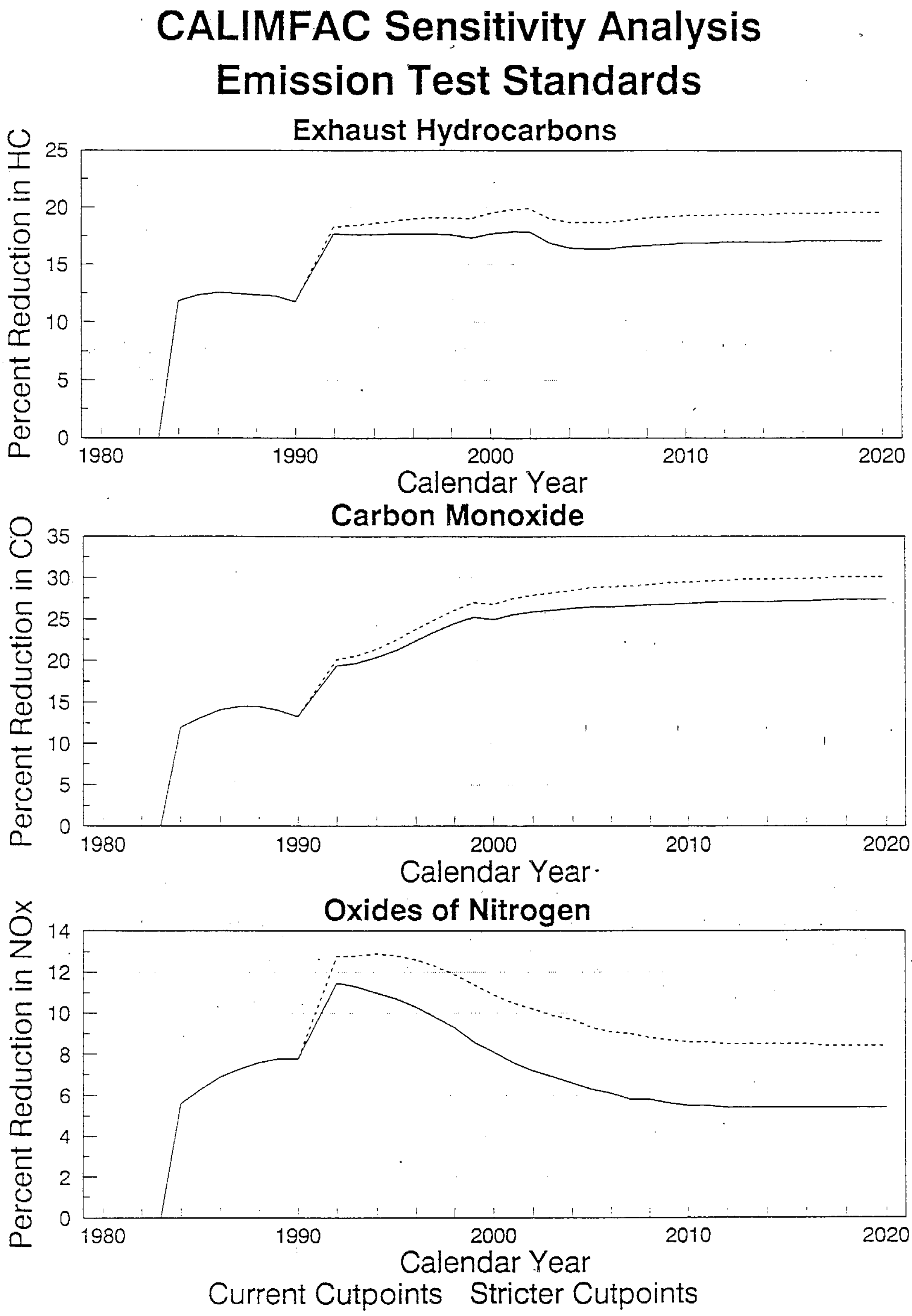
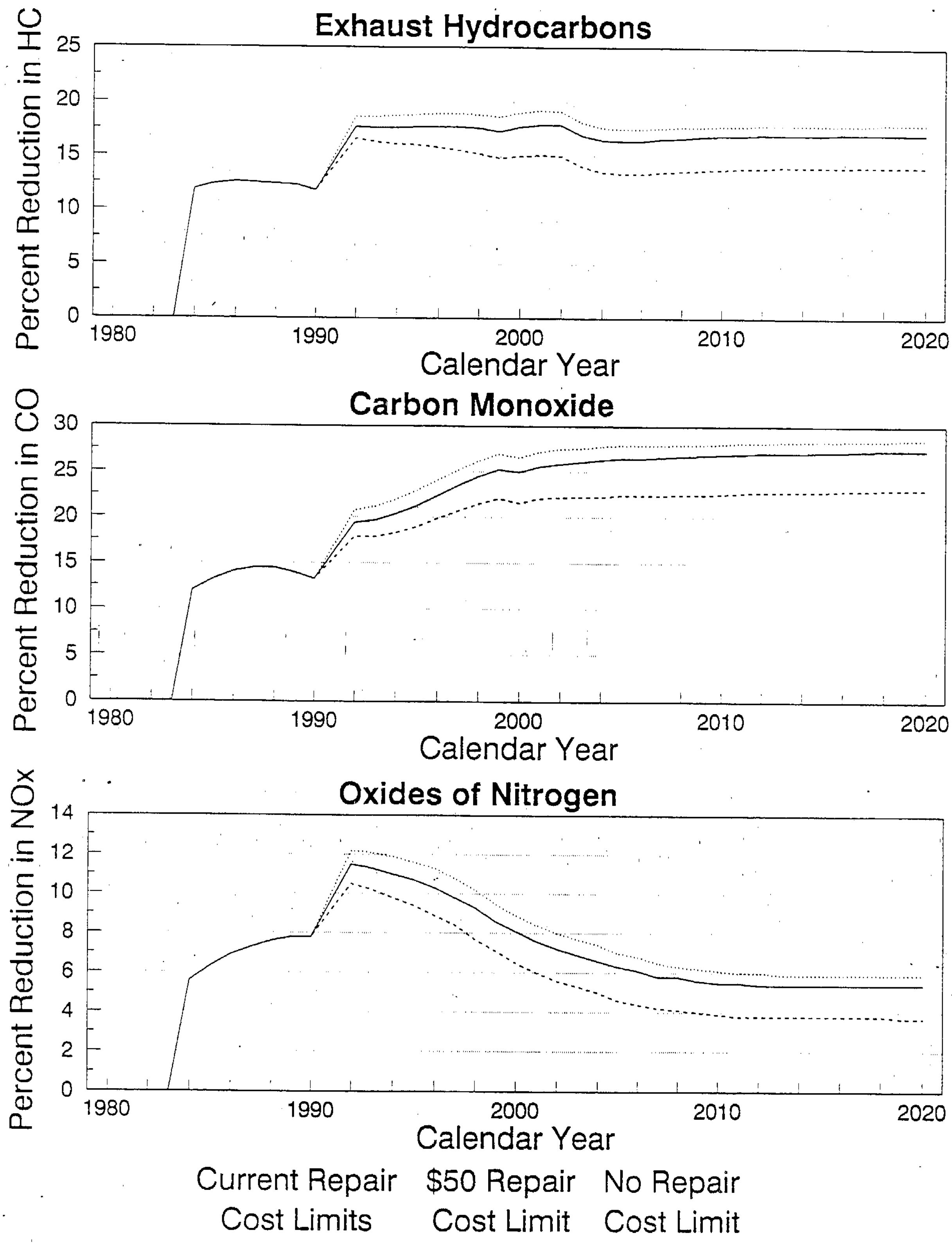

CALIMFAC Sensitivity Analysis
Emission Test Standards
Exhaust Hydrocarbons
Percent Reduction in HC
25
20
15
10
5
0
1980
1990
2000
2010
2020
Calendar Year
Carbon Monoxide
Percent Reduction in CO
35
30
25
20
15
10
5
0
1980
1990
2000
2010
2020
Calendar Year
Oxides of Nitrogen
Percent Reduction in NOx
14
12
10
8
6
4
2
0
1980
1990
2000
2010
2020
Calendar Year
Current Cutpoints
Stricter Cutpoints

Figure V-8

CALIMFAC Sensitivity Analysis
Repair Cost Limits



ceiling for 1980 and later model year vehicles beyond $500. Therefore, the modeling analysis accounts only for small increases in the effectiveness of repair due to removing the limits on pre-1980 model year cars. As described in Section IV.H, the correction efficiencies were based on repairs performed by ARB mechanics. These correction efficiencies were then adjusted to reflect the limitations imposed by repair cost limits. To analyze the effect of removing all repair cost limits, in effect to go beyond the correction efficiency established by ARB mechanics, it would be necessary to examine each vehicle in the data base and make an engineering judgment about how much further emissions could be reduced if additional repairs were performed.

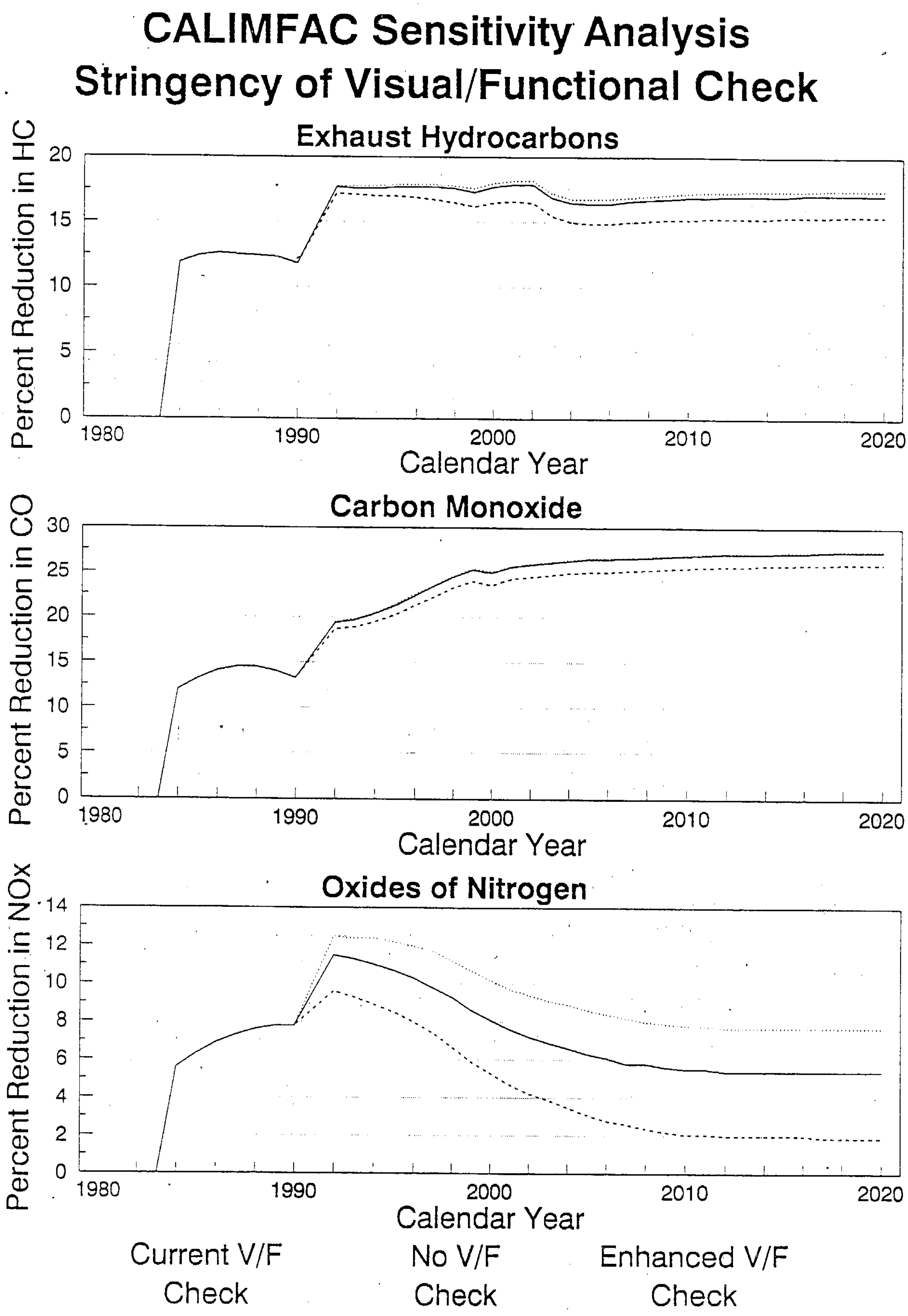
6. Visual/Functional Checks

Increasing the number of components inspected has a very small effect on the overall effectiveness of the baseline I/M program for HC and CO, but is predicted to result in a marked improvement in NOx benefits. Eliminating the visual/functional checks also has the largest detrimental effect on NOx program benefits. These results are shown in Figure V-9. The effectiveness of the checks in failing vehicles with malfunctioning components is limited by the ability of mechanics to identify the malfunctions. An analysis of various visual/functional checks would show more difference between program options if a higher level of mechanic performance was evaluated.

7. Mechanic Performance

The model also appears to be very sensitive to assumptions about mechanic performance. This is to be expected, because mechanic performance affects both the identification rates and the correction efficiencies used in calculating benefits. While the fact that improved mechanic performance results in marked program improvements is not disputed, the actual degree of improvement is difficult to quantify. As described in Section IV.G. and IV.H., the quantification

Figure V-9


CALIMFAC Sensitivity Analysis
Stringency of Visual/Functional Check
Exhaust Hydrocarbons
Percent Reduction in HC
20
15
10
5
0
1980
1990
2000
2010
2020
Calendar Year
Carbon Monoxide
Percent Reduction in CO
30
25
20
15
10
5
0
1980
1990
2000
2010
2020
Calendar Year
Oxides of Nitrogen
Percent Reduction in NOx
14
12
10
8
6
4
2
0
1980
1990
2000
2010
2020
Calendar Year
Current V/F Check
No V/F Check
Enhanced V/F Check

of the effects of mechanic performance on identification and repair rates was highly subjective.

Improved levels of mechanic performance appear to improve program benefits significantly, even if no other changes are made to the program. These improvements are shown in Figure V-10. Based on the assumptions detailed in Section IV., the stricter licensing requirements implemented as a result of recent legislation have produced a noticeable improvement in benefits for all three pollutants.

Computer-assisted diagnosis and repair would further increase HC benefits by over 9%, to nearly 20%, in 2001, and CO benefits by 8% to 29% in the same year. NOx benefits due to computer-assistance also improve slightly, peaking at 12.4% in 1990 and level off at 6.4% about 2010.

8. Vehicle Exemptions

The baseline program exempts vehicles more than 20 years old from the I/M program. One alternative evaluated here was to include in the baseline program vehicles up to 25 years old (see Figure V-11). The CALIMFAC model predicts that this change would produce minor improvements in the mid-1990s, and that these benefits would be further reduced for all pollutants by 2000. This is attributable mostly to the fact that the VMT fraction for older vehicles is extremely small. Vehicles between 21 and 25 years of age account for barely one percent of the VMT each year. Even when their emissions are relatively high, such as the pre-1980 vehicles, their contribution to total emissions, and thus to I/M program benefits, is very small. In later program years, as the relatively dirty cars leave the fleet,

Figure V-10

CALIMFAC Sensitivity Analysis
Mechanic Performance

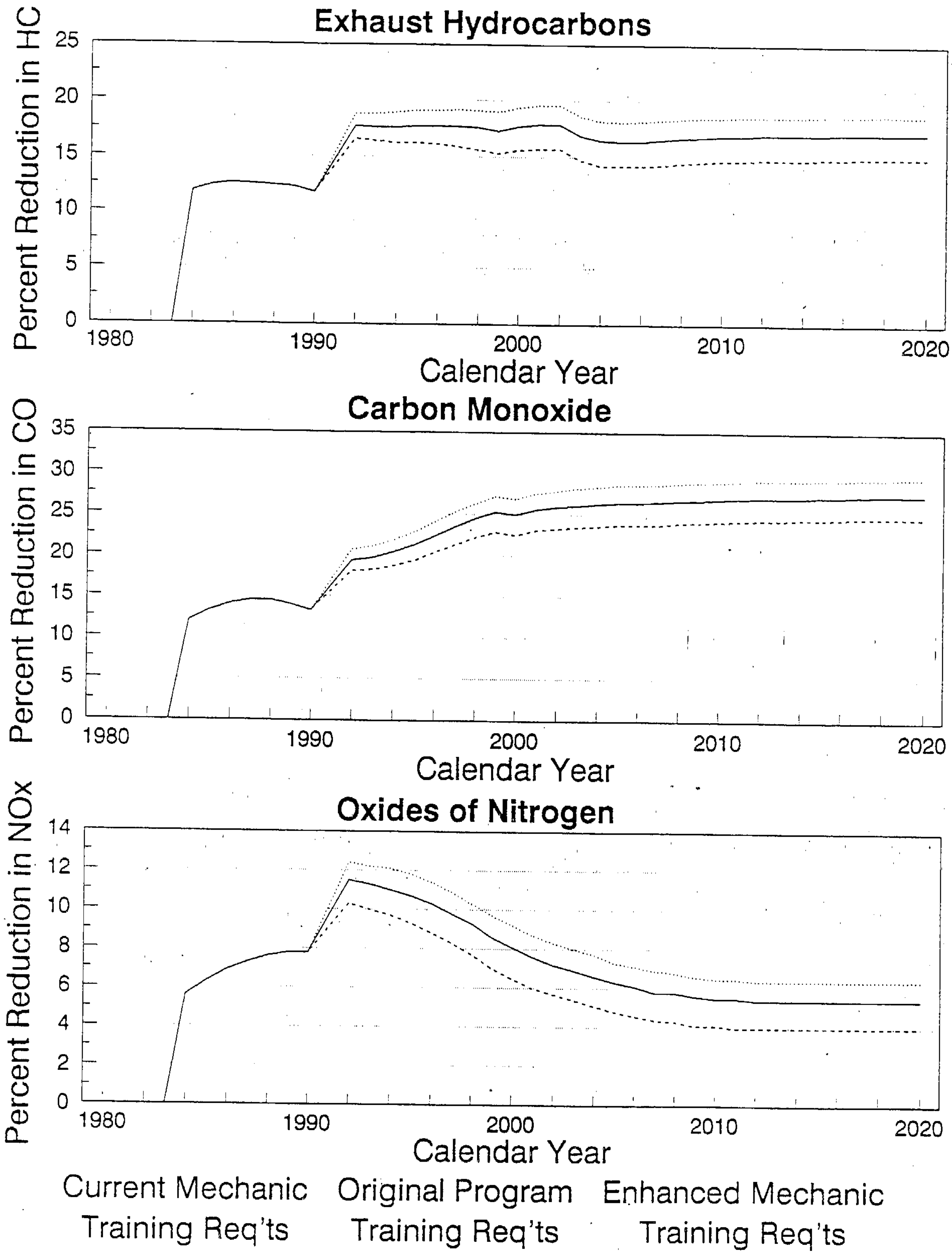
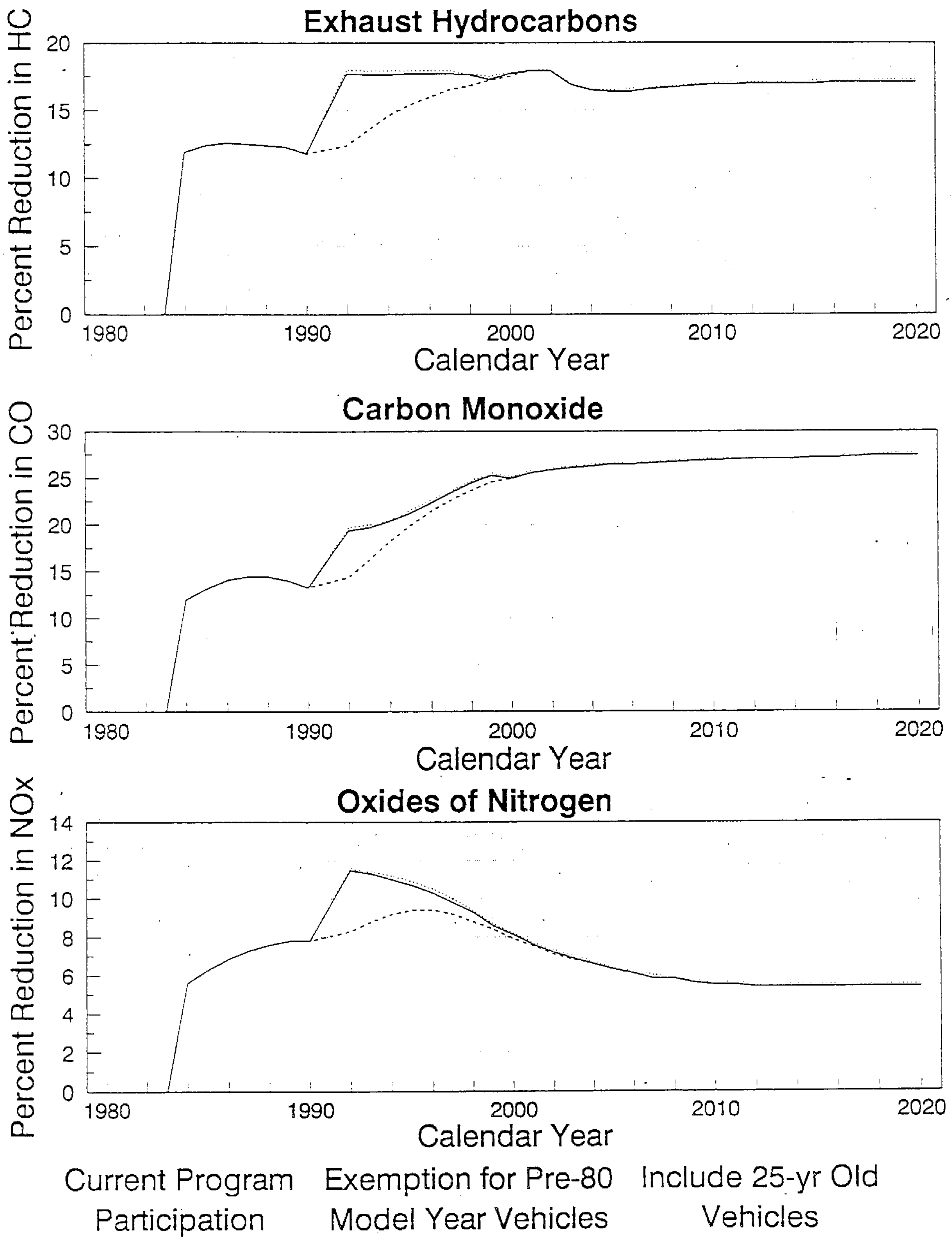


Figure V-11

CALIMFAC Sensitivity Analysis
Vehicle Exemptions



the contribution of the 21 to 25-year-old vehicles to I/M benefits becomes even smaller.

Exempting pre-1980 vehicles from the I/M program would cause a significant reduction in program benefits until the late 1990s. At that time approximately 90 percent of on-road vehicles, accounting for 97% of the VMT, would be subject to inspection.

9. New-Vehicle Exemptions

A two-year exemption for new cars is projected to reduce HC and CO benefits of the baseline program only slightly; a five-year exemption produces a more significant impact. However, a two-year exemption actually improves NOx benefits slightly, because repairs to reduce HC and CO emissions in new vehicles tend to increase NOx emissions slightly in vehicles without malperformances. These effects are shown in Figure V-12.

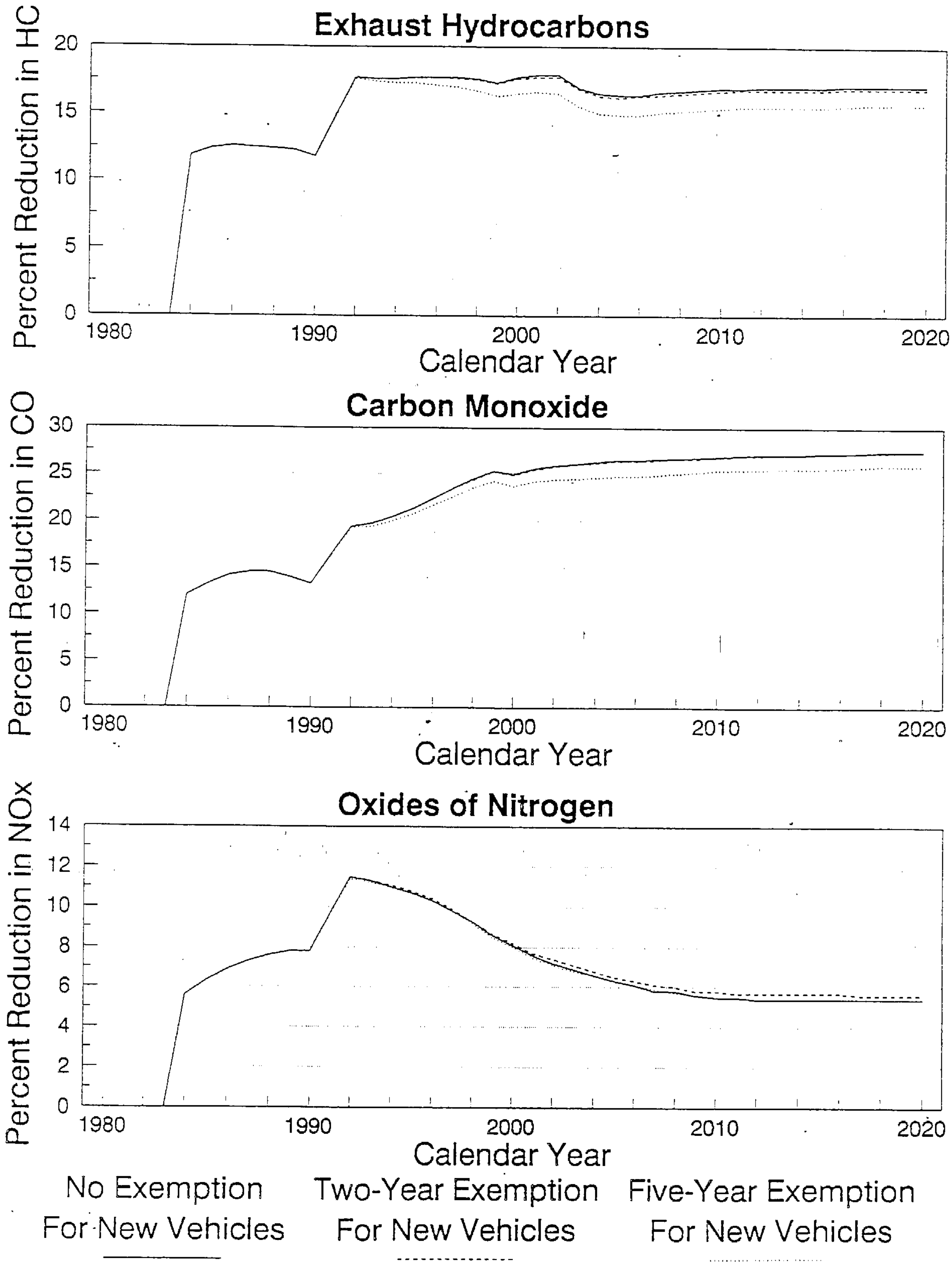
VI. Validating the Model Predictions

This model has been developed as a result of extensive and detailed data analysis, and the results of the sensitivity analysis discussed in Section V indicate that the model predictions are reasonable and internally consistent. However, it is desirable to have some external validation of the model predictions to further confirm the reasonableness and relative accuracy of the results.

Two approaches to validating the model were considered. The first approach was to compare the CALIMFAC predictions of the benefits of various program scenarios with the calculations made in the previous I/M Evaluation Program for similar scenarios. This comparison is discussed further below.

Figure V-12

CALIMFAC Sensitivity Analysis
New-Vehicle Exemptions



The second approach would use data gathered under future surveillance programs for validating the CALIMFAC calculations of benefits. However, there are many difficulties inherent in such an approach, given the fact that most of the California vehicle fleet has been subjected to some form of I/M program for over seven years. This makes the selection of a "control" group (one that has not been through any I/M program) difficult. A validation of this type may be performed by CARB during its next major surveillance program.

A. Comparison of Model Predictions with Manual Calculations

1. Current Smog Check Program

The benefits predicted by CALIMFAC correspond reasonably well with the benefits calculated manually by Sierra Research in "Evaluation of the California Smog Check Program." Table VI-1 shows a comparison of predicted benefits for passenger cars for the first program cycle.

Table VI-1

Comparison of Predicted Benefits: Baseline Program (1985)

	--- Pollutant ---		
	HC	CO	NOx
Model	12.4%	13.2%	5.6%
Manual Calculation	12.3	9.8	3.9

2. Inspection Frequency

CALIMFAC predicts that implementing an annual Smog Check program could double program benefits for all pollutants in the early 1990s. This is due to the high contribution of late '70s and early '80s model vehicles to excess emissions in this time period, combined with relatively poor mechanic performance assumed in the base I/M programs.

The dramatic increase is due to the mechanics' getting a "second try" at each vehicle under the annual program during each two year period.

Over the long term, CALIMFAC predicts that an annual program will increase HC, CO and NOx benefits by five to 10 percent. These predictions are consistent with the 3-5% benefits estimated in the Smog Check Evaluation. These latter calculations probably underestimated the benefits slightly in that they accounted for the benefits of identifying excess emitters ("should fail" vehicles), which were not detected in the biennial program but would be identified in the subsequent, in this case annual, test. However, they did not appear to include the benefits of identifying additional failing vehicles in the subsequent test that deteriorated into the "should fail" emissions regimes before an annual inspection.

3. Emission Test Type

CALIMFAC projections and manual calculations for the potential benefits of incorporating a steady-state loaded mode emissions test in the inspection process are in reasonable agreement, again with the exception of NOx emissions benefits. In "Evaluation of the California Smog Check Program," the use of a steady state loaded mode test is predicted to improve the identification of excess HC emissions by 37% and CO emissions by 42%. Assuming that improvements in identification can be translated directly into improvements in program benefits (that is, assuming the proportion of failing vehicles that are repaired remains the same regardless of which test the vehicle failed), the potential emissions reductions predicted by the manual calculation would be 16.9% for HC and 13.9% for CO.

CALIMFAC predicts slightly smaller HC and CO improvements on a percentage basis: 1 to 3% improvement over the baseline program, compared with the 4 to 5% improvement predicted by the manual calculation. CALIMFAC predicts that NOx benefits would increase by 3 to 5% as well (a one-third improvement) with implementation of a loaded mode program.

In evaluating these results, it is important to remember that if the ability of mechanics to properly repair vehicles is not enhanced, CALIMFAC does not ascribe much benefit to improving the ability to detect vehicles with malfunctions.

4. Enhanced Smog Check Program

The "Evaluation of the California Smog Check Program" included an estimate of potential long-term emission reduction benefits achievable through several program improvements. The improvements included using advanced analyzers, upgrading mechanic qualifications and increasing the cost ceiling on required repairs. The potential benefits calculated in that report were compared with a CALIMFAC evaluation of benefits incorporating comparable program improvements: computer-assisted visual/functional checks, enhanced mechanic performance and a higher cost limit on repairs. The comparison is shown in Table VI-2.

Table VI-2

Comparison of Predicted Benefits: Enhanced Smog Check Program

	-- Pollutant --		
	HC	CO	NOx
Model	28-30%	28-32%	15-16%
Manual Calculation	31	23	20

Again, the model predictions generally agree well with the manual calculations.

In all of these comparisons, it is important to remember that the earlier, manual calculations were focused on a fleet (mid-1980 models) that shows higher benefits due to I/M repairs; the program enhancements discussed above were evaluated for 1990 and later calendar years, since they could not begin in California any earlier than that date.

VII. Conclusions and Recommendations

Comparison of CALIMFAC predictions of emission reduction benefits with manual calculations performed in the "Evaluation of the California Smog Check Program," as well as sensitivity analyses, indicate that the model predictions are accurate, reasonable and consistent overall. The model predicts that the existing program is currently (in 1990) reducing HC and CO emissions from passenger cars by approximately 18% and NOx emissions by approximately 11%. Modeling results suggest that these benefits could be improved substantially by the implementation of any one of several program improvements, including annual inspections, loaded mode testing and more stringent mechanic licensing requirements to improve performance.

Additional data collection and analysis could further improve the performance and predictive capabilities of the model. Recommendations for additional work are:

1. Incorporate additional data on new technology vehicles. The existing data base contains very few vehicles from the post-1983 model years, and no post-1986 vehicles. Because of the large VMT fraction attributed to vehicles less than five years old, the emissions behavior of these new-technology vehicles is extremely important in future Smog Check program benefits. Test data from these late model year vehicles should be incorporated into the model as they are collected.

2. Add evaporative emission data. The CALIMFAC model was written to incorporate crankcase, running loss and evaporative emission data; however, the data themselves were not developed. The data should be developed and incorporated into the model.

Appendix A

Emission Test Cutpoints

I/M Cutpoints: Idle and 2500 RPM (as of 10/15/87)

Inspection Test Type: Option 1
Emission Standard Stringency: Option 1

MODEL YEAR	EMISSION CONTROL EQUIPMENT	CYL	EMISSION STANDARD CATEGORY	IDLE HC	IDLE CO	2500 RPM HC	2500 RPM CO
55-65	ALL	5+	1	800	7.0	N/A	N/A
66-70	AI	5+	2	400	3.5	N/A	N/A
66-70	NO AI	5+	3	500	5.5	N/A	N/A
71-74	AI	5+	4	300	2.5	N/A	N/A
71-74	NO AI	5+	5	400	5.5	N/A	N/A
55-67	ALL	4-	6	1200	6.5	N/A	N/A
68-71	AI	4-	7	450	4.5	N/A	N/A
68-71	NO AI	4-	8	700	6.0	N/A	N/A
72-74	AI	4-	9	350	5.0	N/A	N/A
72-74	NO AI	4-	10	350	6.5	N/A	N/A
75-79	NO CAT AI OR NO AI	ALL	11	200	2.5	N/A	N/A
75-79	OX CAT/NO AI	ALL	12	250	3.5	N/A	N/A
75-79	OX CAT/AI	ALL	13	150	1.2	N/A	N/A
75-79	TWC AI OR NO AI	ALL	14	100	1.5	N/A	N/A
1980+	NO CAT AI OR NO AI	ALL	15	150	2.5	220	1.2
1980+	OX CAT/NO AI	ALL	16	150	2.5	220	1.2
1980+	OX CAT/AI	ALL	17	150	1.2	220	1.2
1980+	TWC AI OR NO AI	ALL	18	100	1.0	220	1.2

Stringent Idle and 2500 RPM Cutpoints

Inspection Test Type: Option 1
Emission Standard Stringency: Option 2

MODEL YEAR	EMISSION CONTROL EQUIPMENT	CYL	EMISSION STANDARD CATEGORY	IDLE HC	IDLE CO	2500 RPM HC	2500 RPM CO
55-65	ALL	5+	1	700	5.5	N/A	N/A
66-70	AI	5+	2	350	3.0	N/A	N/A
66-70	NO AI	5+	3	500	5.5	N/A	N/A
71-74	AI	5+	4	250	2.5	N/A	N/A
71-74	NO AI	5+	5	400	5.0	N/A	N/A
55-67	ALL	4-	6	1000	5.5	N/A	N/A
68-71	AI	4-	7	450	4.5	N/A	N/A
68-71	NO AI	4-	8	700	5.5	N/A	N/A
72-74	AI	4-	9	350	3.5	N/A	N/A
72-74	NO AI	4-	10	350	5.0	N/A	N/A
75-79	NO CAT AI OR NO AI	ALL	11	200	2.5	N/A	N/A
75-79	OX CAT/NO AI	ALL	12	250	3.5	N/A	N/A
75-79	OX CAT/AI	ALL	13	150	1.2	N/A	N/A
75-79	TWC AI OR NO AI	ALL	14	100	1.5	N/A	N/A
1980+	NO CAT AI OR NO AI	ALL	15	150	1.5	120	1.0
1980+	OX CAT/NO AI	ALL	16	100	.8	120	1.0
1980+	OX CAT/AI	ALL	17	100	.8	120	1.0
1980+	TWC AI OR NO AI	ALL	18	60	.5	120	1.0

Steady State Loaded Mode Standards

Inspection Test Type: Option 2 (80 and later Model Years)
Inspection Test Type: Option 3 (All Model Years)
Stringency: Option 1

MODEL YEAR	EMISSION CONTROL EQUIPMENT	CYL	EMISSION STANDARD CATEGORY	CRUISE HC	CO	NOX
55-65	ALL	5+	1	400	6.5	N/A
66-70	AI	5+	2	350	4.0	2400
66-70	NO AI	5+	3	350	4.5	3000
71-74	AI	5+	4	175	2.0	2000
71-74	NO AI	5+	5	250	2.8	2900
55-67	ALL	4-	6	400	6.5	N/A
68-71	AI	4-	7	300	4.5	3200
68-71	NO AI	4-	8	300	6.0	3000
72-74	AI	4-	9	250	4.0	1700
72-74	NO AI	4-	10	250	4.0	2600
75-79	NO CAT AI OR NO AI	ALL	11	150	1.5	2100
75-79	OX CAT/NO AI	ALL	12	150	1.5	2200
75-79	OX CAT/AI	ALL	13	100	1.0	1500
75-79	TWC AI OR NO AI	ALL	14	80	1.0	1000
1980+	NO CAT AI OR NO AI	ALL	15	150	1.2	1500
1980+	OX CAT/NO AI	ALL	16	150	1.2	1200
1980+	OX CAT/AI	ALL	17	100	1.0	1200
1980+	TWC AI OR NO AI	ALL	18	80	1.0	800

Stringent Steady State Loaded Mode Standards

Inspection Test Type: Option 2 (80 and later Model Years)
Inspection Test Type: Option 3 (All Model Years)
Emission Standard Stringency: Option 2

MODEL YEAR	EMISSION CONTROL EQUIPMENT	CYL	EMISSION STANDARD CATEGORY	HC	CRUISE CO	NOx
55-65	ALL	5+	1	400	6.5	N/A
66-70	AI	5+	2	350	4.0	2400
66-70	NO AI	5+	3	350	4.5	3000
71-74	AI	5+	4	175	1.5	2000
71-74	NO AI	5+	5	175	1.5	2000
55-67	ALL	4-	6	400	6.5	N/A
68-71	AI	4-	7	300	4.5	3200
68-71	NO AI	4-	8	300	6.0	3000
72-74	AI	4-	9	175	2.0	1700
72-74	NO AI	4-	10	175	2.0	2000
75-79	NO CAT AI OR NO AI	ALL	11	100	1.0	1500
75-79	OX CAT/NO AI	ALL	12	80	.8	1200
75-79	OX CAT/AI	ALL	13	60	.5	1000
75-79	TWC AI OR NO AI	ALL	14	50	.5	600
1980+	NO CAT AI OR NO AI	ALL	15	100	1.0	1500
1980+	OX CAT/NO AI	ALL	16	50	.5	500
1980+	OX CAT/AI	ALL	17	50	.5	500
1980+	TWC AI OR NO AI	ALL	18	50	.5	500

Appendix B

Bag-Specific and Composite Emission Rates by Regime

Note: Emission rates are arranged by technology group and emission regime, and are presented in the following format:

	HC	CO	NOx	EVAP
Bag 1	xxx,	xxx,	xxx,	xxx,
Bag 2	xxx,	xxx,	xxx,	xxx,
Bag 3	xxx,	xxx,	xxx,	xxx,
Composite	xxx,	xxx,	xxx,	xxx,

BLOCK DATA FOR ARB EMISSION FACTOR AND I/M BENEFITS MODEL:
ZERO-MILE EMISSIONS AND DETERIORATION RATES FOR EACH REGIME

Emissions of the Supers

```
Technology Group 1
     * 33.17,  0.00, 0.00,0.00,
     * 33.57,  0.00, 0.00,0.00,
     * 49.46,  0.00, 0.00,0.00,
     * 35.10,390.00, 0.00,0.00,

Technology Group 2
     * 35.53,  0.00, 0.00,0.00,
     * 34.46,  0.00, 0.00,0.00,
     * 30.09,  0.00, 0.00,0.00,
     * 33.48,390.00, 0.00,0.00,

Technology Group 3
     * 13.37,122.19, 0.00,0.00,
     *  4.50,114.28, 0.00,0.00,
     *  3.77, 75.28, 0.00,0.00,
     *  6.17,105.13, 0.00,0.00,

Technology Group 4
     * 17.99,137.82, 0.00,0.00,
     * 13.11,150.49, 0.00,0.00,
     * 10.87, 99.19, 0.00,0.00,
     * 15.28,133.95, 0.00,0.00,

Technology Group 5
     * 13.86,123.19, 0.00,0.00,
     * 11.80,143.92, 0.00,0.00,
     *  9.18,118.71, 0.00,0.00,
     * 11.54,132.91, 0.00,0.00,

Technology Group 6
     * 8.465,101.93, 0.00,0.00,
     * 4.675, 93.78, 0.00,0.00,
     * 8.082,129.07, 0.00,0.00,
     * 7.413,126.09, 0.00,0.00,

Technology Group 7
     * 7.839,122.31, 0.00,0.00,
     * 6.396,169.81, 0.00,0.00,
     * 2.960,121.22, 0.00,0.00,
     * 5.749,146.68, 0.00,0.00,

Technology Group 8
     * 8.039,125.487,5.398,0.00,
     * 5.191,133.240,3.341,0.00,
     * 4.165,108.763,4.181,0.00,
     * 5.499,124.920,3.998,0.00,
```

Technology Group 9

    * 4.638, 98.977,4.200,0.00,
    * 4.965,114.150,3.533,0.00,
    * 3.388, 86.533,4.653,0.00,
    * 4.467,103.727,3.978,0.00,

Technology Group 10

    * 9.511,160.11,0.00,0.00,
    * 6.246,131.49,0.00,0.00,
    * 9.872,152.36,0.00,0.00,
    * 7.875,143.06,0.00,0.00,

Technology Group 11

    * 5.114,96.37,3.88,0.00,
    * 4.634,103.66,2.52,0.00,
    * 3.678,93.49,2.81,0.00,
    * 4.471,99.34,2.88,0.00,

Technology Group 12

    * 8.039,125.487,2.935,0.00,
    * 5.191,133.240,1.834,0.00,
    * 4.165,108.763,2.294,0.00,
    * 5.499,124.920,2.189,0.00,

Technology Group 13

    * 5.114,96.37,2.22,0.00,
    * 4.634,103.66,1.44,0.00,
    * 3.678,93.49,1.61,0.00,
    * 4.471,99.34,1.65,0.00,

Technology Group 14

    * 8.47,165.15,4.95,0.00,
    * 3.75,110.22,4.52,0.00,
    * 2.95,103.01,5.88,0.00,
    * 4.499,120.56,4.99,0.00,

At the request of the ARB staff, the values for Tech Groups 15 and 16 were adjusted by the ratio of the emission standards (0.25/0.39) for NMHC, and (3.4/7.0) for CO.

Technology Group 15

    * 5.153, 60.951,2.935,0.00,
    * 3.328, 64.717,1.834,0.00,
    * 2.670, 52.828,2.294,0.00,
    * 3.525, 60.675,2.189,0.00,

Technology Group 16

    * 3.278, 46.808,2.220,0.00,
    * 2.971, 50.349,1.440,0.00,
    * 2.358, 45.409,1.610,0.00,
    * 2.866, 48.251,1.650,0.00,

Technology Group 17
    * 0.00,0.00;0.00,0.00,
    * 0.00,0.00,0.00,0.00,
    * 0.00,0.00,0.00,0.00,
    * 0.00,0.00,0.00,0.00,

Technology Group 18
    * 0.00,0.00,0.00,0.00,
    * 0.00,0.00,0.00,0.00,
    * 0.00,0.00,0.00,0.00,
    * 0.00,0.00,0.00,0.00,

Technology Group 19
    * 0.00,0.00,0.00,0.00,
    * 0.00,0.00,0.00,0.00,
    * 0.00,0.00,0.00,0.00,
    * 0.00,0.00,0.00,0.00,

Technology Group 20
    * 0.00,0.00,0.00,0.00,
    * 0.00,0.00,0.00,0.00,
    * 0.00,0.00,0.00,0.00,
    * 0.00,0.00,0.00,0.00/

<u>Emissions of the Very Highs</u>

Technology Group 1
    * 22.18, 42.74, 0.00,0.00,
    * 18.00, 46.84, 0.00,0.00,
    * 45.21, 0.00, 0.00,0.00,
    * 18.20,166.36,0.00,0.00,

Technology Group 2
    * 23.47, 42.74, 3.91,0.00,
    * 23.04, 46.84, 2.66,0.00,
    * 45.21, 0.00, 0.00,0.00,
    * 21.81,166.36,6.935,0.00,

Technology Group 3
    * 5.91,86.58,5.84,0.00,
    * 3.53,87.25,3.94,0.00,
    * 2.91,63.87,5.74,0.00,
    * 3.85,80.72,4.83,0.00,

Technology Group 4
    * 9.09,87.82, 7.934,0.00,
    * 5.70,67.63, 5.667,0.00,
    * 3.94,47.04,7.906,0.00,
    * 5.93,66.41,6.761,0.00,

Technology Group 5
* 5.82,87.85,7.029,0.00,
* 4.55,78.56,5.491,0.00,
* 3.63,53.06,7.839,0.00,
* 4.59,73.66,6.454,0.00,

Technology Group 6
* 6.05,74.83,5.516,0.00,
* 4.21,66.20,4.885,0.00,
* 3.95,44.79,6.337,0.00,
* 2.78,63.25,5.455,0.00,

Technology Group 7
* 4.42,110.16,0.00,0.00,
* 2.43, 94.05,0.00,0.00,
* 2.06, 34.71,0.00,0.00,
* 2.77, 81.04,0.00,0.00,

Technology Group 8
* 3.851,64.756,3.041,0.00,
* 2.486,49.547,2.276,0.00,
* 2.177,40.604,2.848,0.00,
* 2.683,50.236,2.592,0.00,

Technology Group 9
* 3.840,66.877,3.11,0.00,
* 2.372,35.673,1.950,0.00,
* 2.045,39.350,2.216,0.00,
* 2.586,53.473,2.266,0.00,

Technology Group 10
* 2.32,153.27,0.00,0.00,
* 2.54, 35.86,0.00,0.00,
* 2.00, 18.27,0.00,0.00,
* 2.35, 54.38,0.00,0.00,

Technology Group 11
* 4.007,71.07,3.072,0.00,
* 2.132,46.61,2.037,0.00,
* 2.273,33.56,2.815,0.00,
* 2.557,48.10,2.463,0.00,

Technology Group 12
* 3.773,64.756,1.660,0.00,
* 2.436,49.547,1.318,0.00,
* 2.153,40.604,1.469,0.00,
* 2.635,50.236,1.431,0.00,

Technology Group 13
* 4.007,71.07,1.755,0.00,
* 2.132,46.61,1.164,0.00,
* 2.273,33.56,1.609,0.00,
* 2.557,48.10,1.407,0.00,

Technology Group 14
* 4.395,153.27,4.35,0.00,
* 1.855,35.86,2.97,0.00,
* 2.582,18.27,3.48,0.00,
* 2.580,54.38,3.40,0.00,

At the request of the ARB staff, the deterioration rates for Tech Groups 15 and 16 are adjusted by the ratio of the emission standards(0.25/0.39) for NMHC, and (3.4/7.0) for CO.

Technology Group 15
* 2.419,31.453,1.660,0.00,
* 1.562,24.066,1.318,0.00,
* 1.380,19.722,1.469,0.00,
* 1.689,24.400,1.431,0.00,

Technology Group 16
* 2.569,34.520,1.755,0.00,
* 1.367,22.639,1.164,0.00,
* 1.457,16.301,1.609,0.00,
* 1.639,23.363,1.407,0.00,

Technology Group 17
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,

Technology Group 18
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,

Technology Group 19
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,

Technology Group 20
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00/

Emissions of the Highs

Technology Group 1

```
* 11.19,116.02,7.396,0.00,
*  9.21,112.76,4.874,0.00,
*  6.49, 92.39,8.172,0.00,
*  8.10,109.55,6.151,0.00,
```

Technology Group 2

```
* 10.98,152.44,4.913,0.00,
*  6.49,106.02,2.778,0.00,
*  4.85, 65.45,6.523,0.00,
*  7.22,104.58,4.662,0.00,
```

Technology Group 3

```
* 4.34,40.52,4.516,0.00,
* 1.45,29.92,3.053,0.00,
* 1.51,22.66,4.597,0.00,
* 2.06,30.21,3.781,0.00,
```

Technology Group 4

```
* 4.76,64.40,5.830,0.00,
* 2.15,26.45,3.848,0.00,
* 2.07,22.63,5.924,0.00,
* 2.81,33.23,4.823,0.00,
```

Technology Group 5

```
* 3.61,51.18,4.829,0.00,
* 2.44,33.12,3.417,0.00,
* 1.93,24.72,5.022,0.00,
* 2.33,34.83,4.150,0.00,
```

Technology Group 6

```
* 2.79,55.26,4.411,0.00,
* 0.76,27.76,2.732,0.00,
* 1.06,22.69,4.283,0.00,
* 1.27,30.93,3.514,0.00,
```

Technology Group 7

```
* 2.84,37.31,0.00,0.00,
* 0.92,19.40,0.00,0.00,
* 1.06,16.22,0.00,0.00,
* 1.35,22.44,0.00,0.00,
```

Technology Group 8

```
* 2.391,35.517,2.151,0.00,
* 0.889,15.537,1.425,0.00,
* 0.920,16.176,1.827,0.00,
* 1.208,19.847,1.687,0.00,
```

Technology Group 9
* 2.684,40.592,2.307,0.00,
* 0.709,17.153,1.419,0.00,
* 0.802,19.490,1.663,0.00,
* 1.144,22.647,1.673,0.00,

Technology Group 10
* 1.82,49.26,4.99,0.00,
* 1.45,43.64,1.89,0.00,
* 1.32,31.76,4.39,0.00,
* 1.49,41.43,3.22,0.00,

Technology Group 11
* 2.675,35.718,2.491,0.00,
* 0.791,17.240,1.287,0.00,
* 0.795,13.083,1.838,0.00,
* 1.183,19.926,1.688,0.00,

Technology Group 12
* 2.350,35.070,1.243,0.00,
* 0.837,14.984,0.825,0.00,
* 0.919,16.700,1.039,0.00,
* 1.172,19.610,0.971,0.00,

Technology Group 13
* 2.603,33.969,1.424,0.00,
* 0.793,18.583,0.736,0.00,
* 0.782,13.398,1.050,0.00,
* 1.165,20.348,0.965,0.00,

Technology Group 14
* 3.223,64.418,3.602,0.00,
* 0.747,24.181,1.796,0.00,
* 0.803,24.662,2.634,0.00,
* 1.270,32.601,2.398,0.00,

Technology Group 15
* 1.506,17.034,1.243,0.00,
* 0.536, 7.278,0.825,0.00,
* 0.589, 8.111,1.039,0.00,
* 0.751, 9.525,0.971,0.00,

Technology Group 16
* 1.669,16.367,1.424,0.00,
* 0.508, 9.026,0.736,0.00,
* 0.501, 6.508,1.050,0.00,
* 0.747, 9.883,0.965,0.00,

Technology Group 17
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,

Technology Group 18
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,

Technology Group 19
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,

Technology Group 20
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00/

<u>Emissions of the Moderates</u>

Technology Group 1
* 6.605,71.95,4.425,0.00,
* 3.863,53.21,2.554,0.00,
* 3.706,36.46,4.992,0.00,
* 4.241,52.54,3.809,0.00,

Technology Group 2
* 7.208,71.95,4.080,0.00,
* 4.333,51.97,2.587,0.00,
* 3.971,40.40,4.580,0.00,
* 4.431,54.98,3.625,0.00,

Technology Group 3
* 2.371,25.06,3.036,0.00,
* 0.464, 9.21,1.758,0.00,
* 0.703, 8.51,2.975,0.00,
* 0.929,12.29,2.360,0.00,

Technology Group 4
* 2.783,37.93,3.614,0.00,
* 0.653, 5.08,2.237,0.00,
* 0.996, 7.79,3.581,0.00,
* 1.199,12.60,2.898,0.00,

Technology Group 5
* 2.504,37.23,3.458,0.00,
* 0.838, 8.95,2.135,0.00,
* 0.843, 9.12,3.257,0.00,
* 1.195,14.86,2.723,0.00,

Technology Group 6

```
* 1.669,36.90,2.610,0.00,
* 0.374, 4.91,1.594,0.00,
* 0.500, 8.12,2.351,0.00,
* 0.588,12.44,2.038,0.00,
```

Technology Group 7

```
* 1.381,36.81,3.023,0.00,
* 0.325, 6.06,1.046,0.00,
* 0.466, 5.92,2.088,0.00,
* 0.591,12.38,1.754,0.00,
```

Technology Group 8

```
* 1.508,21.068,1.401,0.00,
* 0.300,6.426,0.720,0.00,
* 0.477,8.438,0.934,0.00,
* 0.599,10.008,0.919,0.00,
```

Technology Group 9

```
* 1.284,24.158,1.521,0.00,
* 0.304,4.380,0.676,0.00,
* 0.458,7.323,0.952,0.00,
* 0.550,9.324,0.927,0.00,
```

Technology Group 10

```
* 1.514,23.53,2.472,0.00,
* 0.257, 7.53,1.189,0.00,
* 0.393, 7.47,1.898,0.00,
* 0.555,10.86,1.662,0.00,
```

Technology Group 11

```
* 1.533,17.49,1.506,0.00,
* 0.260,7.154,0.779,0.00,
* 0.363,7.084,1.010,0.00,
* 0.552,9.277,0.993,0.00,
```

Technology Group 12

```
* 1.426,20.848,0.801,0.00,
* 0.302,6.149,0.424,0.00,
* 0.503,9.138,0.540,0.00,
* 0.589,10.012,0.533,0.00,
```

Technology Group 13

```
* 1.567,17.209,0.872,0.00,
* 0.255, 7.223,0.443,0.00,
* 0.357, 7.060,0.588,0.00,
* 0.554, 9.247,0.571,0.00,
```

Technology Group 14

```
* 4.848,35.461,4.327,0.00,
* 3.572,5.027,3.336,0.00,
* 3.710,8.529,3.663,0.00,
* 0.556,12.273,1.299,0.00,
```

Technology Group 15
* 0.914,10.126,0.801,0.00,
* 0.193, 2.987,0.424,0.00,
* 0.322, 4.438,0.540,0.00,
* 0.384, 4.863,0.533,0.00,

Technology Group 16
* 1.004, 8.359,0.872,0.00,
* 0.163, 3.508,0.443,0.00,
* 0.229, 3.429,0.588,0.00,
* 0.355, 4.491,0.571,0.00,

Technology Group 17
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,

Technology Group 18
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,

Technology Group 19
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,

Technology Group 20
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00/

<u>Emissions of the Normals at Zero Miles (Intercept)</u>

Technology Group 1
* 3.386,45.66,2.220,0.00,
* 2.423,26.95,1.096,0.00,
* 2.282,22.98,2.830,0.00,
* 2.478,29.74,2.206,0.00,

Technology Group 2
* 1.544,42.14,2.199,0.00,
* 0.763,17.46,1.020,0.00,
* 0.787,17.24,3.082,0.00,
* 1.601,22.49,1.779,0.00,

```
Technology Group 3
     * 1.403,15.94,1.728,0.00,
     * 0.239, 3.25,0.920,0.00,
     * 0.532, 4.22,1.609,0.00,
     * 0.560, 6.15,1.285,0.00,

Technology Group 4
     * 1.564,16.37 ,2.032,0.00,
     * 0.171, 0.814,1.261,0.00,
     * 0.418, 2.09 ,1.860,0.00,
     * 0.511, 4.57 ,1.517,0.00,

Technology Group 5
     * 1.089,14.73,1.791,0.00,
     * 0.111, 1.30,1.084,0.00,
     * 0.143, 2.16,1.526,0.00,
     * 0.321, 3.23,1.278,0.00,

Technology Group 6
     * 0.782,17.52,1.727,0.00,
     * 0.160, 1.25,0.933,0.00,
     * 0.231, 3.03,1.134,0.00,
     * 0.314, 4.15,1.218,0.00,

Technology Group 7
     * 0.993,17.01,1.544,0.00,
     * 0.143, 1.08,0.800,0.00,
     * 0.200, 2.52,1.201,0.00,
     * 0.340, 4.78,1.111,0.00,

Technology Group 8
     * 0.806,10.833,0.819,0.00,
     * 0.108,1.761,0.262,0.00,
     * 0.180,3.666,0.376,0.00,
     * 0.254,4.472,0.417,0.00,

Technology Group 9
     * 0.756,10.823,0.886,0.00,
     * 0.116,1.172,0.351,0.00,
     * 0.243,3.053,0.529,0.00,
     * 0.272,3.868,0.501,0.00,

Technology Group 10
     * 0.794,11.72,1.200,0.00,
     * 0.064, 1.66,0.451,0.00,
     * 0.119, 2.83,0.776,0.00,
     * 0.230, 2.75,0.838,0.00,

Technology Group 11
     * 0.839,8.919,0.870,0.000,
     * 0.083,2.180,0.258,0.000,
     * 0.152,2.413,0.409,0.000,
     * 0.264,3.871,0.426,0.000,
```

Technology Group 12
* 0.802,11.299,0.469,0.00,
* 0.108, 1.880,0.151,0.00,
* 0.178, 2.994,0.215,0.00,
* 0.280, 3.983,0.256,0.00,

Technology Group 13
* 0.872,8.901,0.499,0.000,
* 0.082,1.286,0.147,0.000,
* 0.148,2.390,0.214,0.000,
* 0.267,3.937,0.239,0.000,

Technology Group 14
* 0.886,18.121,1.084,0.00,
* 0.064,1.245,0.488,0.00,
* 0.124,2.292,0.761,0.00,
* 0.291,5.494,0.688,0.00,

Technology Group 15
* 0.514,5.488,0.469,0.00,
* 0.069,0.913,0.151,0.00,
* 0.114,1.454,0.215,0.00,
* 0.180,1.935,0.256,0.00,

Technology Group 16
* 0.559,4.323,0.499,0.000,
* 0.052,0.625,0.147,0.000,
* 0.095,1.161,0.214,0.000,
* 0.171,1.912,0.239,0.000,

Technology Group 17
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,

Technology Group 18
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,

Technology Group 19
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,

Technology Group 20
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00,
* 0.00,0.00,0.00,0.00/

Deterioration of Emissions of the Normals

Technology Group 1
* 0.000,0.00,0.028,0.00,
* 0.000,0.00,0.042,0.00,
* 0.000,0.00,0.013,0.00,
* 0.079,0.00,0.008,0.00,

Technology Group 2
* 0.207,0.00,0.01,0.00,
* 0.113,0.00,0.026,0.00,
* 0.106,0.00,0.00,0.00,
* 0.066,0.00,0.022,0.00,

Technology Group 3
* 0.00,0.000,0.005,0.00,
* 0.00,0.000,0.012,0.00,
* 0.00,0.000,0.004,0.00,
* 0.00,0.232,0.008,0.00,

Technology Group 4
* 0.000,0.670,0.00,0.00,
* 0.000,0.115,0.00,0.00,
* 0.000,0.207,0.016,0.00,
* 0.024,0.256,0.023,0.00,

Technology Group 5
* 0.3616,0.000,0.000,0.00,
* 0.0348,0.000,0.000,0.00,
* 0.1008,0.000,0.015,0.00,
* 0.1211,0.346,0.018,0.00,

Technology Group 6
* 0.00,0.000,0.00,0.00,
* 0.00,0.000,0.00,0.00,
* 0.00,0.000,0.00,0.00,
* 0.00,0.142,0.00,0.00,

Technology Group 7
* 0.024,0.00,0.043,0.00,
* 0.000,0.00,0.00,0.00,
* 0.000,0.00,0.00,0.00,
* 0.000,0.00,0.00,0.00,

Technology Group 8
* 0.0000,0.136,0.000,0.00,
* 0.001,0.107,0.011,0.00,
* 0.005,0.000,0.012,0.00,
* 0.007,0.00,0.007,0.00,

Technology Group 9
* 0.00,0.00,0.00,0.00,
* 0.0112,0.039,0.005,0.00,
* 0.00,0.114,0.00,0.00,
* 0.010,0.00,0.006,0.00,

Technology Group 10
* 0.035,0.000,0.121,0.00,
* 0.008,0.000,0.0000,0.00,
* 0.016,0.000,0.084,0.00,
* 0.016,0.474,0.000,0.00,

Technology Group 11
* 0.034,0.173,0.016,0.00,
* 0.0000,0.000,0.011,0.00,
* 0.0000,0.069,0.019,0.00,
* 0.006,0.00,0.014,0.00,

Technology Group 12
* 0.000,0.000,0.000,0.00,
* 0.0016,0.0385,0.0068,0.00,
* 0.0067,0.289,0.0068,0.00,
* 0.007,0.138,0.000,0.00,

Technology Group 13
* 0.0297,0.2103,0.0093,0.00,
* 0.000,0.218,0.0054,0.00,
* 0.0013,0.1009,0.018,0.00,
* 0.0055,0.1827,0.0097,0.00,

Technology Group 14
* 0.032,0.00,0.017,0.00,
* 0.015,0.329,0.00,0.00,
* 0.041,0.240,0.00,0.00,
* 0.00,0.00,0.002,0.00,

At the request of the ARB staff, the deterioration rates for Tech Groups 15 and 16 are adjusted by the ratio of the emission standards (0.25/0.39) for NMHC, and (3.4/7.0) for CO.

Technology Group 15
* 0.0000,0.0000,0.0000,0.0000,
* 0.0010,0.0187,0.0068,0.0000,
* 0.0043,0.1404,0.0068,0.0000,
* 0.0045,0.0670,0.0000,0.0000,

Technology Group 16
* 0.0190,0.1021,0.0093,0.0000,
* 0.0000,0.1059,0.0054,0.0000,
* 0.0008,0.0490,0.0180,0.0000,
* 0.0035,0.0887,0.0097,0.0000,

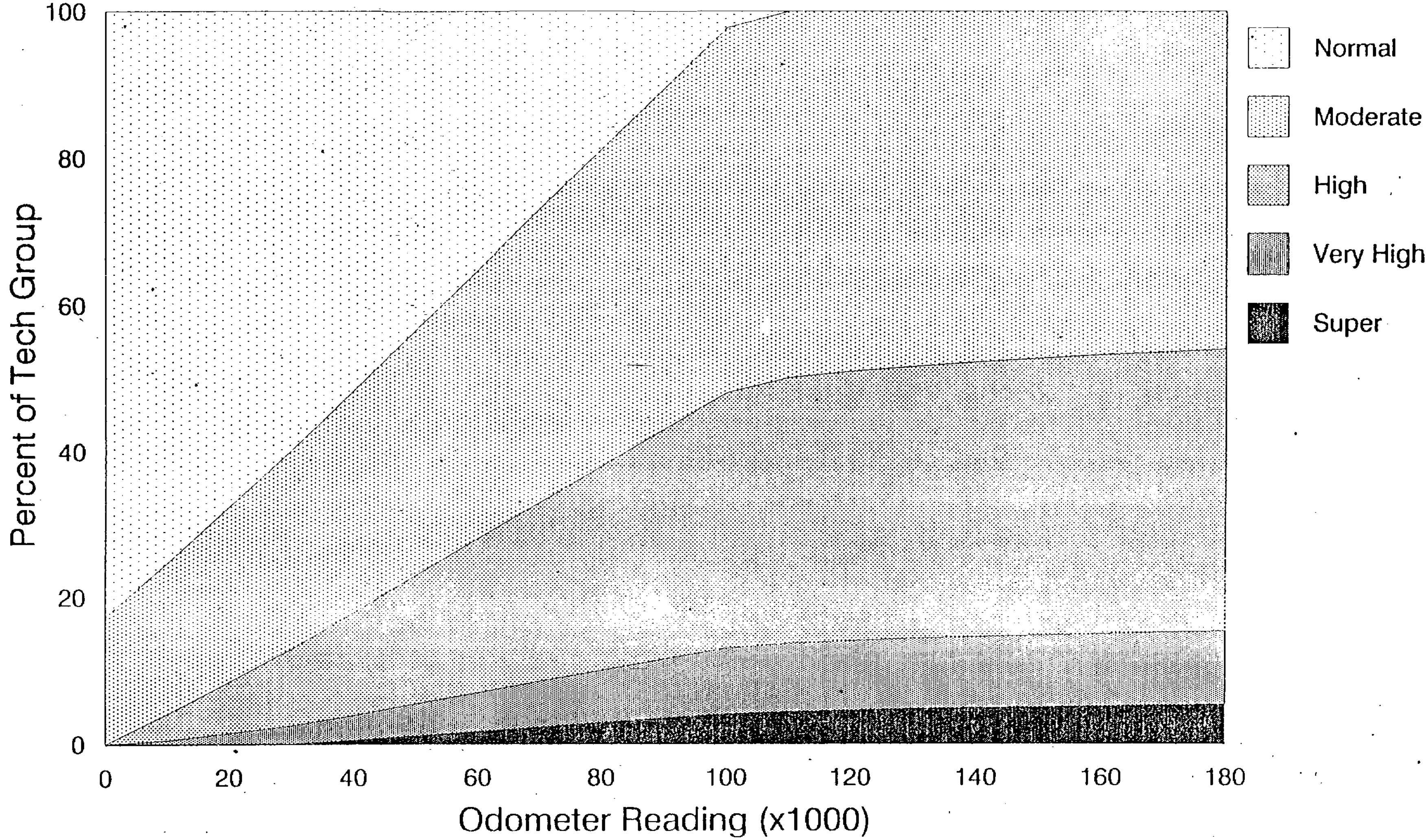
Technology Group 17

```
     * 0.00,0.00,0.00,0.00,
     * 0.00,0.00,0.00,0.00,
     * 0.00,0.00,0.00,0.00,
     * 0.00,0.00,0.00,0.00,

Technology Group 18
     * 0.00,0.00,0.00,0.00,
     * 0.00,0.00,0.00,0.00,
     * 0.00,0.00,0.00,0.00,
     * 0.00,0.00,0.00,0.00,

Technology Group 19
     * 0.00,0.00,0.00,0.00,
     * 0.00,0.00,0.00,0.00,
     * 0.00,0.00,0.00,0.00,
     * 0.00,0.00,0.00,0.00,

Technology Group 20
     * 0.00,0.00,0.00,0.00,
     * 0.00,0.00,0.00,0.00,
     * 0.00,0.00,0.00,0.00,
     * 0.00,0.00,0.00,0.00/
```

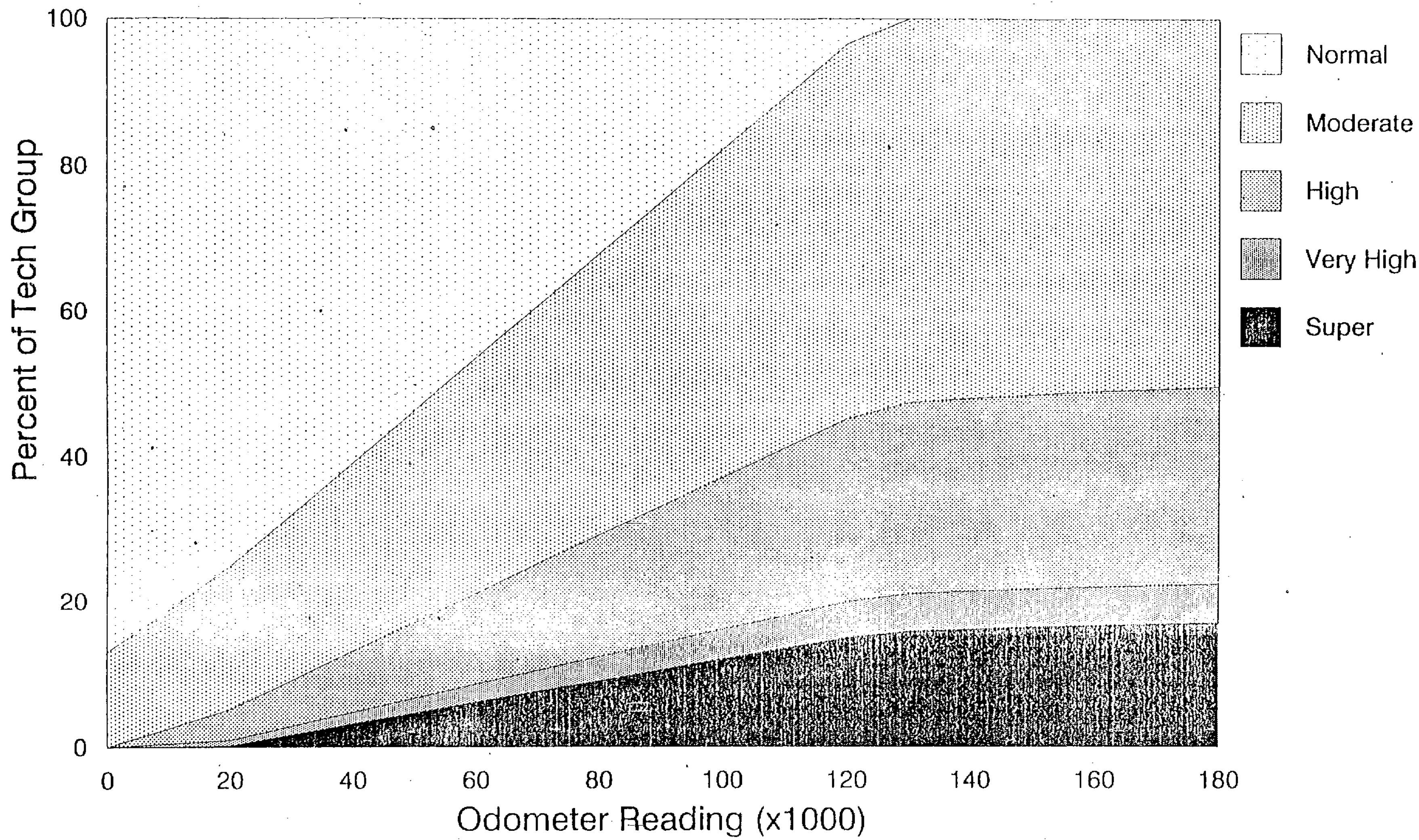
Appendix C

Sample Population Functions for Emissions Regimes
by Technology Group and Pollutant

Population Functions: Technology Group 12 Hydrocarbons



Population Functions: Technology Group 12 Oxides of Nitrogen



Appendix D

Methodology Used for Developing Age-Odometer Relationship From Smog Check Data

Developing Age-Odometer Relationship from TAS Data

1. Calculate vehicle age from date of test and model year of vehicle:

   $$\text{Vehicle Age} = \text{Test Year} - \text{Model Year} + \frac{(\text{Test Month} + 2.5)/2}{12}$$

   to reflect introduction of model year in October of previous year, and sales distributed over the following twelve months.

2. Run regressions on four forms of equation:

   a) $Odo = A + B * Age$

   b) $Odo = A * \exp(B * Age)$

   c) $Odo = A + B * \log(Age)$

   d) $Odo = A * Age^{B}$

3. Choose best fit and form of curve:

   $$\text{Odometer} = -97694 + 165253.9 * \log_{10}(\text{Vehicle Age (years)} + 4)$$

4. Calculate age of vehicle on July 1 of each year:

Year	Age
1	$0.375 * \frac{(3+6)/2}{12}$
2	$1.25 * \frac{(3+12)/2}{12}$
n	$(n-1) + 0.25$

5. Use equation from (3) above to calculate odometer readings corresponding to July 1 ages.

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